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Bale Bicentennial Publications

CONTRIBUTIONS TO MINERALOGY
AND PETROGRAPHY

Yale Bicentennial Publications

With the approval of the President and Fellows of Yale University, a series of volumes has been prepared by a number of the Professors and Instructors, to be issued in connection with the Bicentennial Anniversary, as a partial indication of the character of the studies in which the University teachers are engaged.

This series of volumes is respectfully dedicated to

The Graduates of the University

Geol.

CONTRIBUTIONS
TO
MINERALOGY AND
PETROGRAPHY

FROM THE LABORATORIES OF THE
SHEFFIELD SCIENTIFIC SCHOOL
OF
YALE UNIVERSITY

EDITED BY
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P R E F A C E

THIS volume comprises a series of reprints of some of the most important of the papers containing the results of the researches made in the Chemical, Mineralogical, and Petrographical laboratories at Yale in the lines of Mineralogy and Petrography. It is believed that, gathered from various scattered sources and put into this compact and permanent form, they will prove a useful addition to the literature of these closely-allied sciences. It is thought, also, that the historical accounts of the development of these sciences in Yale University will prove of interest, and the appended bibliographies will indicate the scope and character of the work which has been undertaken and the results which have been attained. The mineralogical portion of the volume has been written or edited by S. L. PENFIELD; the petrographical part, by L. V. PIRSSON.

YALE UNIVERSITY, NEW HAVEN,
May, 1901.

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EDITED BY S. L. PENFIELD.

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PART I.—MINERALOGY

EDITED BY

S. L. PENFIELD

HISTORY OF THE MINERALOGICAL DEPARTMENT AND OF THE DEVELOPMENT OF MINERALOGY AT YALE.

By S. L. PENFIELD.

THE study of Science at Yale may be considered as having had its beginning in 1802, when Benjamin Silliman was appointed Professor of Chemistry and Mineralogy in the College. The influence of Professor Silliman upon the early development of mineralogy and in other scientific directions at Yale was of great importance, for he was a careful observer, an enthusiastic teacher, and he had the faculty of inspiring others with a zeal and spirit for investigation. Soon after the appointment of Professor Silliman, Colonel George Gibbs of Rhode Island, for many years a resident in Europe, returned from his travels with a collection of minerals described as being at that time the most extensive and valuable ever brought to this country. Professor Silliman visited Colonel Gibbs, spending much time with him in studying the collection, with the result that Colonel Gibbs made the generous and unexpected proposition to open his cabinet at Yale College, provided rooms should be fitted up for its reception. To this proposition prompt response was made by the authorities of the College, and in 1810, 1811, and 1812, the collection was arranged and placed at the disposition of the public under the personal supervision of Colonel Gibbs. In 1825 the collection was offered for sale, preference being given to Yale as purchaser. Mainly through the influence of Professor Silliman, the necessary funds (\$20,000) were secured and the collection became the property of the College, serving as the nucleus of the present Yale College Collection.

Another factor which has had undoubtedly a great influence upon the development of mineralogy at Yale was the founding, in 1818, of the American Journal of Science and Arts, at New Haven, by Professor Silliman. Most American contributions to mineralogy have appeared in the pages of this journal, and, naturally, the editors have been consulted through a long series of years upon subjects pertaining to this special department of science.

In 1846, Benjamin Silliman, Jr., was appointed to the Professorship of Applied Chemistry and John Pitkin Norton to the Professorship of Agricultural Chemistry. In the year following, these gentlemen opened an analytical laboratory for students on the college grounds, in the house formerly occupied by President Day. This was the beginning of the department which, owing to the beneficence of the late Joseph E. Sheffield of New Haven, has since grown into the Sheffield Scientific School of Yale University. Chemistry and mineralogy were, so to speak, the corner-stones upon which the School was built, and there have always been professors, instructors, and students in the mineralogical and chemical laboratories who have taken great interest in mineralogical investigations. The long list of papers, emanating in the early days of the School from its chemical and later from its mineralogical laboratory, are the strongest evidence which can be produced of the active part which Yale has taken in the development of the science of mineralogy. These papers, a list of which will be found in the bibliography, indicate the importance which it has been felt by those connected with the department should be attached to the chemical investigation of mineral substances.

In 1850, James Dwight Dana was appointed to the Silliman Professorship of Geology, and in 1864, Mineralogy was added to the title. While Professor Dana's publications on subjects pertaining to mineralogy and crystallography were numerous, he was more interested in the broader questions of crystallogeny, isomorphism, and the classification of species, than in the details of the characters of individual minerals.

His ability to take the scattered observations of others and arrange them in concrete, classified form was remarkable. In 1837, while assistant in the department of chemistry, geology, and mineralogy he published the first edition of his *System of Mineralogy*, "including an extended treatise on crystallography with an appendix containing the applications of mathematics to crystallographic investigation." Enlarged editions of the *System of Mineralogy* appeared in 1844, 1850, 1854, and in 1868, the last being for many years the standard work on the subject, not alone for America, but for the world. It was a surprise to most scientists of Europe that a system of mineralogy, like that of Professor Dana's, could be produced in America, since at that time there had been very few contributions to the science of mineralogy from our country. In 1892 Professor Edward S. Dana entirely rewrote and much enlarged his father's work. This is known as the *Sixth Edition of Dana's System of Mineralogy*. These editions of Dana's *System of Mineralogy* have served to make Yale College known throughout the entire scientific world as a center for mineralogy, and it is doubtful whether any other place at home or abroad has exerted a like influence.

In 1855 a professorship of Metallurgy was founded in the Scientific School, and George J. Brush was appointed to fill the chair. Professor Brush, a graduate of the class of 1852, had prepared himself by study abroad for work along the lines of mineralogy, metallurgy, and chemistry, but mineralogy was the subject which most interested him. Accordingly the title of his professorship was changed in 1864 to that of mineralogy. In 1872 Professor Brush became director of the Sheffield Scientific School, but he retained his professorship of mineralogy and continued to give courses of lectures to the students until about 1890. Although so great a part of his time had to be devoted to the executive work demanded by his position as director of the Scientific School, he nevertheless continued his investigations, and conducted with the aid of his students important researches. He has always taken an active interest in all investigations undertaken in the laboratory, and has

greatly aided the younger workers both by his advice and also by supplying them with materials for investigation from his private collection of minerals. Professor Brush published his first paper on mineralogy in 1850, when he was a student in the old analytical laboratory on the college grounds. His later publications are noted in the bibliography, with the exception of three important papers on the Reëxamination of American Minerals, published in 1853 with Professor J. Lawrence Smith, with whom he was associated for a short time at the University of Virginia. The eighth, ninth and tenth Supplements to the fourth edition of Dana's System of Mineralogy were prepared by Professor Brush. He also aided Professor Dana in the preparation of the fifth edition of the System of Mineralogy, and afterwards prepared the first appendix to it. In 1874 he published a Manual of Determinative Mineralogy, which has since been very extensively used.

While a student at Yale, Professor Brush became interested in making a collection of minerals, and during the period of the past fifty years his collection has grown till it now numbers over 15,000 specimens. The value of a collection, however, must not be estimated from the number of specimens it contains, but rather from its importance as a means of education and from the scientific results which have been obtained from it. One of the main objects which Professor Brush has constantly kept in mind has been to bring together mineral specimens for purposes of study and investigation. The Brush Collection is not on public exhibition, nor is it intended that such a disposition shall be made of it, but for convenient reference and study it is kept in cabinets of drawers.

Since the foundation of the Sheffield Scientific School the collection has been used for illustrating the lectures on crystallography and general descriptive mineralogy, which are given each year to the students. The collection is, moreover, a storehouse of material for investigation, and it has an inestimable historical value, since it contains the type speci-

mens of the large number of minerals which have been investigated in the mineralogical and chemical laboratories at Yale. Although the collection and the extensive mineralogical library accompanying it are the private property of Professor Brush, they are deposited in the Peabody Museum and the University has the benefit of their full and unrestricted use.

The Yale University Collection, of which the Gibbs Collection, already referred to, is the nucleus, is distinct from the Brush Collection. It is contained in one of the exhibition rooms of the Peabody Museum, and is in charge of Professor Edward S. Dana, who has been Curator since 1874. The collection, attractively displayed, is accessible at all times, not only to students, but also to the public. It contains much material for study and investigation, and many type specimens of minerals which have been described. To the Yale University Mineral Collection belong also the valuable and extensive Yale Collection of Meteorites and the Blum Collection of Pseudomorphs. The collection of pseudomorphs is that of the late Professor J. Reinhard Blum of the University of Heidelberg, purchased by Yale College in 1872. Professor Blum was an authority on the subject of pseudomorphs and the collection contains the types described by him in his standard work, *Die Pseudomorphosen des Mineralreichs*.

Professor Edward S. Dana's numerous contributions to the science of mineralogy are noted in the bibliography, and it is probable that his works, comprising the Sixth Edition of Dana's System of Mineralogy (1892), Text Book of Mineralogy (1877 and 1898), and Minerals and How to Study Them (1895), are more extensively used than any other books pertaining to mineralogy. Professor Dana has also succeeded his father and grandfather as Editor of the American Journal of Science.

In 1873 George W. Hawes was appointed Assistant in Mineralogy, but he soon specialized along the lines of petrography. His love for science and his enthusiasm were inspirations to all who knew him, and the writer has always considered it a great privilege to have been one of his students. A sketch of Dr. Hawes's life and a bibliography of his

publications, prepared by Professor Pirsson, are given in this volume.

In 1879 the present writer, a graduate of the class of 1877, and for two years Assistant in Analytical Chemistry in the Sheffield Laboratory, was appointed as Assistant in Mineralogy. In 1888 he became Assistant Professor, and in 1893 Professor of Mineralogy. In 1898 he rewrote and much enlarged Professor Brush's *Manual of Determinative Mineralogy and Blowpipe Analysis*. At different times the following men have been associated with the writer as assistants and instructors in mineralogy: E. O. Hovey, E. S. Sperry, O. C. Farrington, L. V. Pirsson, J. H. Pratt, C. H. Warren, and W. E. Ford. The devotion of these men to their work, and their love for science, have rendered possible the publication of the long series of investigations which are cited in the bibliography.

Most cordial relations have always existed between the departments of chemistry and mineralogy in the Sheffield Scientific School. In the early days of the school mineral analyses were all made in the Sheffield Chemical Laboratory, and it was not until 1881 that a special analytical laboratory was provided for the mineralogical department. Professor H. L. Wells, a graduate of the class of 1877, was appointed instructor in Analytical Chemistry in 1884, and in 1888 he became Assistant Professor, in 1893 Professor of Analytical Chemistry and Metallurgy. In addition to his investigations in chemistry he has made many important contributions to mineralogy, as may be seen from the titles given in the bibliography. Dr. H. W. Foote, also of the chemical department, has contributed much to our knowledge of the chemical composition of minerals. Many of the papers of Professor Wells and of Dr. Foote appear in full in the pages of this volume. On the other hand those connected with the mineralogical department have devoted much time to the examination of crystals of new and rare compounds made in the chemical laboratory. Thus the two departments help and supplement one another, for chemistry and crystallography are essential to both.

The bibliography which follows will serve to give some idea of the character of the investigations undertaken, and of the amount of work accomplished in the Yale Laboratories. Following the bibliography are three Summaries of the more important results: the first of these gives the *new species* described; the second the minerals whose chemical formulas have been determined; and the third the minerals whose crystalline characters have been established.

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SUMMARY OF THE NEW MINERAL SPECIES DESCRIBED FROM THE YALE LABORATORIES.

- Beryllonite; by E. S. Dana and H. L. Wells, 1888, 1889. A phosphate of sodium and beryllium, NaBePO_4 , from Stoneham, Maine. Crystallization orthorhombic.
- Bixbyite; by S. L. Penfield and H. W. Foote, 1897. A combination of iron and manganese oxides, essentially FeMnO_3 , from near Simpson, Utah. Crystallization isometric, indicating that the mineral is related to perovskite, CaTiO_3 .

- Canfieldite; by S. L. Penfield, 1894. Essentially a sulphostannate of silver, $\text{Ag}_8\text{SnS}_6 = 4\text{Ag}_2\text{S} \cdot \text{SnS}_2$, with a little of the isomorphous germanium molecule Ag_8GeS_6 , from Potosi, Bolivia. Crystallization isometric.
- Clinohedrite; by S. L. Penfield and H. W. Foote, 1898. A silicate and hydroxide of zinc and calcium $[\text{ZnOH}][\text{CaOH}]\text{SiO}_3$, from Franklin, N. J. Crystallization monoclinic, clinohedral group.
- Cookeite; by G. J. Brush, 1866. A hydrated silicate of aluminium, lithium, and potash, related to the micas, from Hebron and Paris, Maine.
- Dickinsonite; by G. J. Brush and E. S. Dana, 1878. A normal phosphate, $\text{R}_3[\text{PO}_4]_2 \cdot \frac{1}{2}\text{H}_2\text{O}$, where $\text{R} = \text{Mn}, \text{Fe}, \text{Ca}, \text{Na}_2, \text{K}_2$ and Li_2 , from Branchville, Connecticut. Crystallization monoclinic.
- Durangite; by G. J. Brush, 1869. A fluo-arsenate of aluminium, iron, and sodium, $\text{Na}[\text{AlF}]\text{AsO}_4$, with some Fe isomorphous with Al, from Durango, Mexico. Crystallization monoclinic.
- Durdenite; by E. S. Dana and H. L. Wells, 1890. A tellurite of ferric iron, $\text{Fe}_2[\text{TeO}_3]_3 \cdot 4\text{H}_2\text{O}$, from the Ojojoma District, Honduras.
- Eosphorite; by G. J. Brush and E. S. Dana, 1878. A hydrated phosphate of aluminium and manganese $[\text{AlO}]\text{MnPO}_4 \cdot 2\text{H}_2\text{O}$, with a little Fe isomorphous with Mn, from Branchville, Connecticut. The mineral is related to childrenite $[\text{AlO}]\text{FePO}_4 \cdot 2\text{H}_2\text{O}$. Crystallization orthorhombic.
- Eucryptite; by G. J. Brush and E. S. Dana, 1880. An orthosilicate of aluminium and lithium, LiAlSiO_4 , resulting from the alteration of spodumene, from Branchville, Connecticut. Crystallization hexagonal.
- Fairfieldite; by G. J. Brush and E. S. Dana, 1879. A hydrated phosphate, $\text{R}_3[\text{PO}_4]_2 \cdot 2\text{H}_2\text{O}$, where $\text{R} = \text{Ca}, \text{Mn},$ and Fe , from Branchville, Connecticut. Crystallization triclinic.
- Fillowite; by G. J. Brush and E. S. Dana, 1879. A hydrated phosphate, $\text{R}_3[\text{PO}_4]_2 \cdot \frac{1}{2}\text{H}_2\text{O}$, where $\text{R} = \text{Mn}, \text{Fe}, \text{Ca},$ and Na_2 , from Branchville, Connecticut. Crystallization monoclinic.
- Gerhardtite; by H. L. Wells and S. L. Penfield, 1885. A basic nitrate of copper, $[\text{CuOH}]\text{NO}_3 \cdot \text{Cu}[\text{OH}]_2$, from Jerome, Arizona. Crystallization orthorhombic.
- Glaucochroite; by S. L. Penfield and C. H. Warren, 1899. An orthosilicate of calcium and manganese, CaMnSiO_4 , from Franklin, New Jersey. Glaucochroite is related to monticellite, CaMnSiO_4 . Crystallization orthorhombic.
- Graftonite; by S. L. Penfield, 1900. A normal phosphate

- $R_2[PO_4]_2$, R = Fe, Mn, and Ca, from Grafton, New Hampshire. Crystallization monoclinic. The material is curiously intergrown with triphylite.
- Hamlinite; by W. E. Hidden and S. L. Penfield, 1890. A phosphate, occurring very sparingly with herderite at Stoneham, Maine. Crystallization hexagonal, rhombohedral.
- Hancockite; by S. L. Penfield and C. H. Warren, 1899. A silicate related to epidote and piedmontite, but containing a considerable quantity of lead, from Franklin, New Jersey. Crystallization monoclinic.
- Hortonolite; by G. J. Brush, 1869. An orthosilicate, R_2SiO_4 , where R = Fe, Mn, and Mg, from Monroe, New York. Hortonolite is related to fayalite, and is intermediate between fayalite and chrysolite. Crystallization orthorhombic.
- Jefferisite; by G. J. Brush, 1866. A hydrated micaceous mineral belonging to the vermiculite group, from Westchester, Pennsylvania.
- Leucophœnicite; by S. L. Penfield and C. H. Warren, 1899. A manganese silicate, $Mn_5[MnOH]_2[SiO_4]_3$, with a little Zn and Ca isomorphous with the Mn, from Franklin, New Jersey. Leucophœnicite is equivalent to a manganese humite.
- Lithiophilite; by G. J. Brush and E. S. Dana, 1878. Essentially $LiMnPO_4$, with a little Fe isomorphous with Mn, from Branchville, Connecticut. Lithiophilite is related to triphylite, $LiFePO_4$. Crystallization orthorhombic.
- Nasonite; by S. L. Penfield and C. H. Warren, 1899. A mesosilicate, $Pb_4[PbCl]_2Ca_4[Si_2O_7]_3$, from Franklin, New Jersey. Nasonite is related to ganomalite, $Pb_4[PbOH]_2Ca_4[Si_2O_7]_3$. Crystallization tetragonal.
- Natrophilite; by G. J. Brush and E. S. Dana, 1890. Essentially $NaMnPO_4$, with some Fe isomorphous with Mn, from Branchville, Connecticut. Crystallization orthorhombic.
- Nesquehonite; by F. A. Genth and S. L. Penfield, 1890. A hydrated magnesium carbonate $MgCO_3 \cdot 3H_2O$, from Nesquehonig, Schuylkill Co., Pennsylvania. Crystallization orthorhombic.
- Pearceite; by S. L. Penfield, 1896. Essentially Ag_3AsS_6 , equivalent to an arsenical polybasite, from Marysvale, Lewis and Clarke Co., Montana. Crystallization monoclinic.
- Pirssonite; by J. H. Pratt, 1896. A hydrated carbonate of sodium and calcium, $Na_2CO_3 \cdot CaCO_3 \cdot 2H_2O$, from San Bernardino Co., California. Crystallization orthorhombic, hemimorphic.
- Ralstonite; by G. J. Brush, 1871. A hydrous fluoride of aluminum, sodium, and magnesium, from Arksuk-fiord, West Greenland. Crystallization isometric.

- Reddingite; by G. J. Brush and E. S. Dana, 1878. A normal phosphate, $\text{Mn}_3[\text{PO}_4]_2 \cdot 3\text{H}_2\text{O}$, with Fe isomorphous with Mn, from Branchville, Connecticut. Crystallization orthorhombic.
- Roebbingite; by S. L. Penfield and H. W. Foote, 1897. A complex silicate of calcium and lead containing a sulphite radical, $\text{H}_{10}\text{Ca}_7\text{Pb}_2\text{Si}_5\text{S}_2\text{O}_{28}$, from Franklin, New Jersey.
- Selen-tellurium; by E. S. Dana and H. L. Wells, 1890. A combination of selenium and tellurium from Tegucigalpa, Honduras.
- Spangolite; by S. L. Penfield, 1890. A hydrated sulphate and chloride of copper and aluminium $[\text{AlCl}]\text{SO}_4 \cdot 6\text{Cu}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$, from near Tombstone, Arizona. Crystallization hexagonal-rhombohedral, hemimorphic.
- Sperryite; by H. L. Wells, 1889. Arsenide of platinum, PtAs_2 , from the district of Algoma, Ontario, Canada. Crystallization isometric-pyritohedral.
- Sussexite; by G. J. Brush, 1868. A borate, HRBO_3 , where $\text{R} = \text{Mn}, \text{Mg}$, and a little Zn, from Franklin, New Jersey.
- Triploidite; by G. J. Brush and E. S. Dana, 1878. A phosphate, $\text{R}[\text{ROH}]\text{PO}_4$, where $\text{R} = \text{Mn}$ and Fe, from Branchville, Connecticut. Crystallization monoclinic. Triploidite is closely related to triplite, $\text{R}[\text{RF}]\text{PO}_4$, where $\text{R} = \text{Mn}$ and Fe, and to wagnerite, $\text{Mg}[\text{MgF}]\text{PO}_4$, and its discovery was of especial importance as it illustrated in a simple and striking manner the isomorphous relations of hydroxyl and fluorine in the radicals $[\text{ROH}]$ and $[\text{RF}]$.
- Tysonite; by O. D. Allen and W. J. Comstock, 1880. A fluoride of the rare-earth metals, $[\text{Ce}, \text{La}, \text{Di}]\text{F}_3$, from Pike's Peak, Colorado. Crystallization hexagonal.
- Wellsite; by J. H. Pratt and H. W. Foote, 1897. A silicate $\text{RAl}_2\text{Si}_8\text{O}_{10} \cdot 3\text{H}_2\text{O}$, where $\text{R} = \text{Ca}, \text{Ba}, \text{Sr}, \text{Na}_2$ and K_2 , from Buck Creek, Clay Co., North Carolina. Crystallization monoclinic. Wellsite is closely related to harmotome and phillipsite.

SUMMARY OF MINERALS WHOSE FORMULAS HAVE BEEN DETERMINED IN THE YALE LABORATORIES, EXCLUSIVE OF THOSE GIVEN IN THE PREVIOUS LIST OF NEW MINERALS.

Alunite, $\text{R}[\text{Al}(\text{OH})_2]_2[\text{SO}_4]_2$, $\text{R} = \text{K}$ and Na . This comparatively simple formula was derived from an analysis of alunite from Red Mountain, Colorado, by E. B. Hurlburt, 1893. It was shown that the mineral contains hydroxyl and not water of crystallization.

Alurgite, $\text{HR}_2[\text{AlOH}]\text{Al}[\text{SiO}_3]_4$, $\text{R} = \text{K}$ and (MgOH) . The

mineral belongs to the mica group, and the formula was derived from an analysis by S. L. Penfield, 1893, of a specimen from Piedmont, Italy.

Amblygonite, $\text{Li}[\text{AlF}]\text{PO}_4$ and $\text{Li}[\text{AlOH}]\text{PO}_4$. Analyses of eight varieties of the mineral from different localities by S. L. Penfield, 1879, indicate that the composition may be regarded as mixtures, in varying proportions, of the foregoing isomorphous fluorine and hydroxyl molecules.

Argyrodite, $\text{Ag}_8\text{GeS}_6 = 4\text{Ag}_2\text{S} \cdot \text{GeS}_2$. Analyses of specimens from Bolivia and Saxony by S. L. Penfield, 1893, indicate the foregoing composition and not $3\text{Ag}_2\text{S} \cdot \text{GeS}_2$, as determined by another investigator.

Aurichalcite, $2\text{RCO}_3 \cdot 3\text{R}[\text{OH}]_2$, $\text{R} = \text{Zn}$ and Cu . The formula was derived from two analyses by S. L. Penfield, 1891, of very pure material from unknown localities in Utah.

Childrenite, $\text{Fe}[\text{AlO}]\text{PO}_4 \cdot 2\text{H}_2\text{O}$, a little Mn and Ca isomorphous with Fe . The formula was derived from an analysis of material from Tavistock, Wales, by S. L. Penfield, 1879. The formula was thus shown to be analogous to that of eosphorite $\text{Mn}[\text{AlO}]\text{PO}_4 \cdot 2\text{H}_2\text{O}$. Water is all expelled at a low temperature; hence the mineral contains no hydroxyl.

Chondrodite, and the minerals of the chondrodite group, humite and clinohumite. From analyses of four specimens of chondrodite, two of humite and two of clinohumite by S. L. Penfield and W. T. H. Howe, 1891, it was shown that the minerals of this group form a series differing from one another by a molecule of Mg_2SiO_4 as follows:

Chondrodite	$\text{Mg}_8[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_2$
Humite	$\text{Mg}_5[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_3$
Clinohumite	$\text{Mg}_7[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_4$

In the radical $[\text{Mg}(\text{F}, \text{OH})]$ fluorine and hydroxyl are regarded as isomorphous.

Clinohumite, $\text{Mg}_7[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_4$, see Chondrodite.

Connellite, $\text{Cu}_{15}[\text{Cl}, \text{OH}]_4\text{SO}_{16} \cdot 15\text{H}_2\text{O}$. The formula of this basic combination of a sulphate and chloride of copper was derived from an analysis by S. L. Penfield, 1890, made on 0.0740 grams of the exceedingly rare material from Cornwall, England.

Cookeite, $\text{Li}[\text{Al}(\text{OH})_2]_3[\text{SiO}_3]_2$. Formula derived from an analysis by S. L. Penfield, 1893, of material from Paris, Maine.

Ganomalite, $\text{Pb}_4[\text{PbOH}]_2\text{Ca}_4[\text{Si}_2\text{O}_7]_3$. This formula is made probable by the investigation of the new mineral Nasonite, the corresponding chlorine compound, $\text{Pb}_4[\text{PbCl}]_2\text{Ca}_4[\text{Si}_2\text{O}_7]_3$, by S. L. Penfield and C. H. Warren, 1899.

Hamlinite, $[\text{Al}(\text{OH})_2]_3[\text{Sr}(\text{OH})]\text{P}_2\text{O}_7$, with some Ba isomorphous with Sr. The formula was derived from an analysis by S. L. Penfield, 1897, of material from Oxford Co., Maine.

Hanksite, $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$. This complex formula, containing three acid radicals, is derived from an analysis by S. L. Penfield, 1885, and two analyses by J. H. Pratt, 1896, on entirely different samples of material from San Bernardino Co., California.

Herderite, $\text{Ca}[\text{Be}(\text{F},\text{OH})]\text{PO}_4$. The formula indicating the isomorphous relations of the radicals $[\text{BeF}]$ and $[\text{BeOH}]$ was established by an analysis of the mineral from Stoneham, Maine, by S. L. Penfield and D. N. Harper, 1886.

Howlite, $\text{H}_6\text{Ca}_2\text{B}_5\text{SiO}_{14}$. This formula was derived from an analysis by S. L. Penfield and E. S. Sperry, 1887, of exceptionally pure material from Windsor, Nova Scotia. The analysis served to give howlite the rank of a well defined mineral species.

Humite, $\text{Mg}_3[\text{Mg}(\text{F},\text{OH})]_2[\text{SiO}_4]_3$, see Chondrodite.

Hydro-herderite $\text{Ca}[\text{BeOH}]\text{PO}_4$. The existence of a variety of herderite free from fluorine was established by an analysis by H. L. Wells, 1892, of a specimen from Hebron, Maine.

Ilmenite, $\text{RO} \cdot \text{TiO}_2$, where $\text{R} = \text{Fe}$ and Mg . That ilmenite is a combination of FeO and TiO_2 , in other words a titanate of iron, and not an isomorphous mixture of Fe_2O_3 and Ti_2O_3 , is shown by an analysis by H. W. Foote, 1897, of crystallized ilmenite from Orange Co., New York, containing a large proportion of MgO . The presence of MgO in the mineral indicates that the iron must exist in the ferrous condition as FeO , with which MgO is isomorphous.

Iolite, $[\text{Mg}, \text{Fe}]_4\text{Al}_3[\text{OH}]_2[\text{Si}_2\text{O}_7]_5$. Two analyses of exceptionally pure material by O. H. Farrington, 1892, served to establish the foregoing formula.

Jarosite $\text{K}[\text{Fe}(\text{OH})_2]_3[\text{SO}_4]_2$. This formula follows as a result of the investigation of the isomorphous compound Alunite by E. B. Hurlburt, page 24.

Kentrolite, $[\text{Mn}_4\text{O}_8]\text{Pb}_3[\text{SiO}_4]_3$. This formula follows as a result of the investigation of the isomorphous compound Melanotekite by C. H. Warren.

Leadhillite, $\text{Pb}_2[\text{PbOH}]_2[\text{SO}_4][\text{CO}_3]_2$. Formula established by an analysis by H. L. Wells, 1894, of very pure material from Granby, Missouri.

Melanotekite, $[\text{Fe}_4\text{O}_8]\text{Pb}_3[\text{SiO}_4]_3$. Formula established by an analysis by C. H. Warren, 1898, of material from Hillsboro, New Mexico. The formula of the isomorphous mineral kentrolite was shown to be $[\text{Mn}_4\text{O}_8]\text{Pb}_3[\text{SiO}_4]_3$ as a result of this investigation.

Monazite, $[\text{Ce,La,Di}]\text{PO}_4$, with admixture of ThSiO_4 . The presence of the molecule ThSiO_4 was shown by three analyses by S. L. Penfield, 1882, and a later analysis by S. L. Penfield and E. S. Sperry, 1888. It was pointed out in the original investigation that ThSiO_4 was present in monazite as an impurity, but it seems more probable from later considerations that ThSiO_4 crystallizes with CePO_4 as an isomorphous constituent.

Mordenite, $[\text{Ca,Na}_2\text{K}_2]\text{Al}_2\text{Si}_9\text{O}_{22} \cdot 6\text{H}_2\text{O}$. Derived by L. V. Pirsson, 1890, from an analysis of material from the Yellowstone National Park.

Northupite, MgCO_3 , Na_2CO_3 , NaCl . Formula established by J. H. Pratt, 1896, from an analysis of crystals from San Bernardino Co., California.

Parisite, $[\text{RF}]_2\text{Ca}[\text{CO}_3]_3$, where R = Ce, La, and Di. Formula established by two analyses by C. H. Warren, 1899, on crystallized material from Ravalli Co., Montana, and Muso, U. S. Colombia.

Pollucite, $\text{H}_2\text{Cs}_4\text{Al}_4[\text{SiO}_3]_9$. Derived from analyses by H. L. Wells, 1891, of material from Hebron, Maine.

Ralstonite, $[\text{Mg,Na}_2]\text{Al}_3[\text{F,OH}]_{11} \cdot 2\text{H}_2\text{O}$. An analysis by S. L. Penfield and D. N. Harper, 1886, indicates that the mineral contains both water of crystallization and hydroxyl. The hydroxyl when taken as isomorphous with the fluorine leads to the foregoing formula.

Spodumene, $\text{LiAl}[\text{SiO}_3]_2$, with a little Na isomorphous with Li. The foregoing simple formula was derived by G. J. Brush, 1850, from two analyses of the mineral from Norwich and Sterling, Massachusetts. It was subsequently shown by Rammelsberg that the mineral had a far more complicated composition, and it was not until 1878 that, as a result of a reinvestigation of the mineral by Doelter, the simple composition derived by Professor Brush was re-established.

Staurolite, $[\text{AlO}]_4[\text{AlOH}]\text{Fe}[\text{SiO}_4]_2$, with Mg isomorphous with Fe. The foregoing formula was derived from four analyses by S. L. Penfield and J. H. Pratt, 1894, of carefully purified materials.

Sulphohalite, $2\text{Na}_2\text{SO}_4$, NaCl , NaF . Derived from an analysis by S. L. Penfield, 1900, of the exceedingly rare material from San Bernardino Co., California. The formula is interesting as indicating the existence of three acid constituents in a single compound.

Topaz, $[\text{AlF}]_2\text{SiO}_4$ with admixture of the isomorphous hydroxyl compound $[\text{AlOH}]_2\text{SiO}_4$. The existence of the hydroxyl molecule was shown by analyses of six varieties of topaz by S. L. Penfield and J. C. Minor, 1894. The optical properties of

topaz, which had previously been regarded as anomalous, were shown to be dependent upon the presence of the hydroxyl molecule in greater or less amount.

Tourmaline, $H_9Al_3B_2[OH]_2Si_4O_{19}$, the nine hydrogen atoms being replaced in varying amounts by metals of varying valence, Al, Fe, Mn, Mg, Ca, Na, K, Li. Fluorine replaces part of the hydroxyl. The empirical formula of the tourmaline acid, $H_{18}B_2[OH]_2Si_4O_{19}$, was established by two analyses of most carefully selected materials, by S. L. Penfield and H. W. Foote, 1899, and it was shown that the many excellent analyses of other investigators yield the same result.

Turquoise, $[Al(OH)_2, Fe(OH)_2, Cu(OH), H]_3PO_4$, in part $[Al(OH)_2, Fe(OH)_2, Cu(OH)]_2HPO_4$. Turquoise seems to be a derivative of normal phosphoric acid, H_3PO_4 , in which the hydrogen atoms are replaced in part by the univalent radicals $[Al(OH)_2]$, $[Fe(OH)_2]$ and $[Cu(OH)]$. The formula was derived by S. L. Penfield, 1900, from an analysis of turquoise from Lincoln Co., Nevada.

SUMMARY OF MINERALS WHOSE CRYSTALLIZATION HAS BEEN ESTABLISHED IN THE YALE LABORATORIES, EXCLUSIVE OF THOSE GIVEN IN THE PREVIOUS LIST OF NEW MINERALS.

Amarantite:—Crystallization triclinic. Axial ratio determined and forms described. S. L. Penfield, 1890.

Argyrodite:—Crystallization determined to be isometric and not monoclinic as formerly supposed. S. L. Penfield, 1893.

Bertrandite:—The hemimorphic character of the species was established by the study of crystals from Stoneham, Maine, and Mt. Antero, Colorado. S. L. Penfield, 1888.

Danburite:—Crystallization established as orthorhombic, axial ratio determined and forms described. G. J. Brush and E. S. Dana, 1880.

Herderite:—Crystallization monoclinic. It was shown that the orthorhombic habit which the mineral generally exhibits results from twinning. S. L. Penfield, 1894.

Lansfordite:—Crystallization triclinic; axial ratio established and forms described. S. L. Penfield, 1890.

Metacinnabarite:—Crystallization isometric and tetrahedral, thus indicating that the mineral, HgS , belongs in the same group with sphalerite, ZnS . S. L. Penfield, 1885.

Mordenite:—Crystallization monoclinic. Axial ratio established and forms described by L. V. Pirsson, 1890.

- Penfieldite: — Crystallization established as hexagonal, and axial ratio determined. S. L. Penfield, 1894.
- Polianite: — Crystallization tetragonal. Axial ratio determined and forms described. It was shown that the mineral, MnO_2 , crystallizes like cassiterite and rutile, SnO_2 and TiO_2 respectively, and belongs in the same group with them. E. S. Dana and S. L. Penfield, 1888.
- Polybasite: — Crystallization monoclinic. Axial ratio determined and forms described. The article includes a discussion of the similarity in crystalline form between chalcocite, Cu_2S , and a number of sulphantimonites and sulpharsenites in which Cu_2S or its isomorphous equivalent, Ag_2S , predominates. S. L. Penfield, 1896.
- Sperryllite: — Crystallization isometric and pyritohedral, thus showing that the mineral, PtAs_2 , is analogous to pyrite, FeS_2 . S. L. Penfield, 1889.
- Tiemannite: — Crystallization isometric and tetrahedral, thus indicating that the mineral, HgSe , belongs in the same group with sphalerite, ZnS . S. L. Penfield, 1885.
- Willemite: — An examination of crystals from the Merritt Mine, New Mexico, and Franklin, New Jersey, showed the existence of rhombohedrons of three orders, thus indicating that willemite, Zn_2SiO_4 , crystallizes like phenacite, Be_2SiO_4 , in the tri-rhomboidal division of the hexagonal system. S. L. Penfield, 1894.

The foregoing list refers only to minerals, and does not include the determination of the crystallization of a large number of chemical substances, especially series of new double salts made in the Sheffield Chemical Laboratory. A list of these contributions to crystallography by S. L. Penfield, H. L. Wheeler, J. H. Pratt, H. W. Foote and C. H. Warren may be found in the Bibliography between the years 1892 and 1897.

ON AMERICAN SPODUMENE.

By GEORGE J. BRUSH,
Of the Yale Analytical Laboratory.*

(From Amer. Jour. Sci., 1850, vol. 10, pp. 370-371.)

Read before the American Association for the Advancement of Science at
New Haven, August, 1850.

OWING to the want of a complete analysis of an American Spodumene, I was induced, at the suggestion of Prof. Silliman, Jr., to undertake this research.

The Spodumene from Utö has often been the subject of chemical investigation and has been analyzed by Arfvedson,† Stromeyer,‡ Regnault,§ and Hagen.|| That from the Killiney locality has been analyzed by Thomson.¶

These are all the complete analyses recorded of this species; partial analyses, however, exist of specimens from the Tyrol mountains, and from Sterling, Mass., the former by Hagen and the latter by both Hagen and Bowen.

The constitution of this mineral was not correctly understood prior to Hagen's analysis, until which time it had been

* This may be considered as the first publication by Professor Brush, although two analyses made by him, one of albite and the other of anorthite, had previously been published in a paper by Professor Silliman, Jr. (Amer. Jour. Sci., 1849, vol. 8, pp. 390-391). It is interesting to note that the oxygen ratio 1 : 3 : 8 derived from the analyses of spodumene led to the simple formula $R_2Al_2Si_4O_{12}$, R_2 being Li_2 , Na_2 , and Ca . Considering R_2 wholly as Li_2 , which is the essential alkali metal, the formula may be further simplified to $LiAlSi_2O_6$. The simple formula derived by Professor Brush was questioned by Rammelsberg (Pogg. Ann., vol. 85, p. 544), and for a long time a more complicated composition was generally assigned to the mineral, until in 1878 the simple and correct formula, determined by Professor Brush, was re-established by Döelter (Tschermak Min. u. Petr. Mitth., vol. 1, p. 517).

† Schweigger's Jour., xxii, 107.

‡ Untersuchungen, i, 426.

§ Ann. des Mines (III. series), 1839, 580.

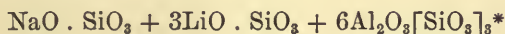
|| Pogg. Ann., xlviii, 371.

¶ Thom. Min., i, 302.

considered as essentially a silicate of alumina and lithia. Hagen, however, found a portion of the so-called lithia to be soda, which discovery being confirmed renders the formulas derived from former analyses incorrect, owing to the great difference in the atomic weights of lithia and soda. Hagen's analysis of a specimen from the Utö locality gave

		Oxygen.		Ratio.	
Silica	66.136	= 34.36	34.36	12.26	12
Alumina . . .	27.024	= 12.63	12.72	4.55	4½
Peroxide of iron	00.321	= 0.09			
Lithia	3.836	= 2.11	2.79	1.00	1
Soda	2.683	= 0.68			
	100.00				

from which he deduced the formula



My analyses agree with Hagen's in the soda, but lead to a different formula. The specimens selected for analysis were from the Norwich and Sterling (Mass.) localities. A qualitative examination of each showed the presence of silica, alumina, peroxide of iron (trace), lime, lithia, and soda.

In the quantitative examination the alkalis were obtained by decomposition by hydrofluoric acid and determined as sulphates; the other constituents were obtained by fusion with carbonate of soda. That from Norwich in two analyses yielded

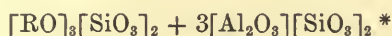
	I.	II.	Mean.	Oxygen.		Ratio.
Silica .	63.06	62.72	62.89	32.67	32.67	8.04
Alumina	28.00	28.85	28.42	13.28	13.28	3.27
Lime .	00.95	1.13	1.04	0.29	4.06	1.00
Lithia .	5.67	5.67	5.67	3.12		
Soda .	2.51	2.51	2.51	0.65		
	100.19	100.88				

* The old method of notation is here employed, the oxides of sodium, lithium, and silicon being regarded as NaO, LiO, and SiO₃, respectively.

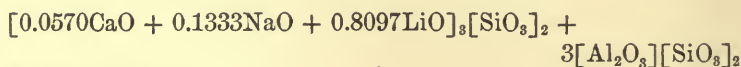
And that from the Sterling locality, of which also two analyses were made, gave

	I.	II.	Mean.	Oxygen.		Ratio.
Silica .	62.86	62.67	62.76	32.61	32.61	7.80
Alumina	28.83	29.83	29.33	13.75	13.75	3.28
Lime .	00.56	00.71	00.63	0.18	4.19	1.00
Lithia .	6.48	6.48	6.48	3.56		
Soda .	1.76	1.76	1.76	0.45		
	<u>100.49</u>	<u>101.45</u>				

The mean of the ratios calculated from the four analyses is 1: 3.27: 7.92 or quite nearly 1: 3: 8, which gives the general formula



And the special formula



which requires,

				Per cent.
8	atoms of silica	4618.48	=	64.14
3	atoms of alumina	1925.40	=	26.76
2.4291	atoms of lithia	441.27	=	6.12
0.3999	atoms of soda	154.84	=	2.15
0.171	atoms of lime	60.10	=	0.83
		<u>7200.09</u>	=	<u>100.00</u>

This formula corresponds quite well with the analyses, especially in the protoxide bases, the mean of which is almost precisely that required by the formula.

* According to the present system of notation this formula becomes $3\text{R}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 12\text{SiO}_2 = \text{RAlSi}_2\text{O}_6$.

ON SUSSEXITE, A NEW BORATE FROM MINE HILL, FRANKLIN FURNACE, SUSSEX CO., NEW JERSEY.

By GEORGE J. BRUSH.

(From Am. Jour. Sci., 1868, vol. 46, pp. 240-243.)

IN examining a specimen of a fibrous mineral, obtained at Mine Hill last year, I found that it was a fibrous silicate of zinc, and being desirous of further investigating the mineral, I requested my assistant, Mr. Wm. G. Mixter, on his recent visit to the locality, to obtain as much of the fibrous substance as possible, so that a quantitative analysis might be made of it. Mr. Mixter was fortunate in obtaining one specimen of what we at first sight took to be the fibrous silicate, but on examination of its pyrognostic characters it proved to be a new mineral, a hydrous fusible borate, reacting strongly with the fluxes for manganese. This interesting discovery led me at once to revisit the locality, and I there succeeded in obtaining enough of the new mineral to give the following characters. It is found in the franklinite vein at the opening on the north end of Mine Hill, associated with franklinite, zincite, willemite, tephroite, calcite and what appears to be a double carbonate of manganese and magnesia occurring implanted on, or imbedded in the fibrous mineral in minute hemispherical forms; it has also, associated with it, a black hydrate of manganese, apparently the species manganite, and a pale pink carbonate which is probably rhodochrosite. The black manganite and the double carbonate have the appearance of being products of the alteration of the borate, since, where associated with these, the latter seems exceedingly friable and evidently in process of decomposition.

The pure mineral is whitish with a tinge of yellow or pink, is translucent on the edges and in thin fragments, and pos-

sesses a silky to pearly luster. The structure is fibrous, sometimes asbestiform, although in other specimens it seems to cleave much more readily in one direction than in a direction at right angles to this, yielding flat fibrous fragments. The mineral occurs in seams in calcite, sometimes with the fibers running transversely, and in other specimens quite long and parallel to the seam. The hardness is slightly above 3, scratching calcite, but not aragonite. Specific gravity = 3.42.

On heating in the closed tube the mineral darkens slightly in color and yields water which reacts neutral to test-papers; but if turmeric paper is moistened with this water, then with a drop of dilute chlorhydric acid and afterwards dried, it assumes the red color characteristic of boric acid, and thus shows that at least a trace of this acid is driven off with the water. In the forceps the mineral fuses in the flame of a candle (F. = 2) and B. B. in O. F. yields a black crystalline mass and colors the flame intensely yellowish-green. With borax and salt of phosphorus it gives a deep amethystine bead in O. F., which in R. F. becomes colorless and transparent. With soda it yields a green manganate.

It is readily dissolved in chlorhydric acid, and most specimens thus treated give off a minute quantity of chlorine, showing traces of a slight alteration of the protoxide of manganese into a higher oxide. On evaporation to dryness and resolution in acid, minute imponderable traces of silica were found. Qualitative analysis proved the presence of boric acid, manganese, magnesia, and water, with questionable traces of zinc and soda. A fragment of the mineral moistened with sulphuric acid and held in the flame of an ordinary Bunsen burner gave, when observed through the spectroscope, the characteristic spectrum of boric acid.

The exceedingly simple composition of the mineral rendered the quantitative determination of the bases comparatively easy. The mineral being dissolved in chlorhydric acid, the excess of acid was driven off and the manganese was thrown down by bromine in the presence of an excess of acetate of soda as hydrated sesquioxide; this was redissolved and

precipitated as ammonio-phosphate and weighed as pyrophosphate. The magnesia was separated from the filtrate from the oxide of manganese (after it was first ascertained that this solution was entirely free from manganese) as ammonio-phosphate and estimated as pyrophosphate. The water was determined by igniting the powdered mineral in a glass tube closed at one end, about 10 inches in length with a caliber of $\frac{1}{4}$ of an inch. The length of the tube effected a complete condensation of the water, which was deposited on the interior five or six inches from the open end, and the tube and contents on being weighed proved to have suffered a loss of less than one milligram by the ignition. The water was then dried out at the ordinary temperature in vacuo over chloride of calcium. To make entirely sure that no boric acid went off with the water, I ignited a portion of the mineral which had previously been thoroughly mixed with about five times its weight of calcined magnesia and then covered with a layer of pure magnesia. The results of this experiment confirmed the water determination made by the above method. The boric acid was determined by Stromeier's method as boro-fluoride of potassium. The results of the analyses are —

	I.	II.	III.	IV.	V.	VI.	Mean.	Oxygen.
Boric acid	...	...	...	...	...	31.89	31.89	22.82
Manganous oxide	40.08	40.20	40.01	...	...	...	40.10	9.04
Magnesia	17.12	16.76	17.21	...	...	...	17.03	6.81
Water	...	...	...	9.64	9.53	...	9.59	8.53
							98.61	

The analysis shows a loss of 1.39 per cent, doubtless due chiefly to the imperfections of the method employed for determining the boric acid. Calculating the loss as boric acid, the total amount of the acid is 33.28 per cent, and the oxygen ratio for B_2O_3 , RO, and H_2O is 22.82 : 15.85 : 8.53, or 3 : 2.08 : 1.12. The ratio 3 : 2 : 1, although not according precisely with the analyses, is nevertheless probably the true ratio. It requires a change of but a few tenths of a per cent of water to make this ratio. In fact, in what appeared to be a fresher and less altered specimen than that above

analyzed, I obtained but 8.93 per cent of water, which would change the amount of boric acid calculated as loss to 33.94 per cent. Correcting the oxygen to correspond to these, we have $B_2O_3 : RO : H_2O = 23.27 : 15.85 : 7.94$, or almost exactly 3 : 2 : 1, or, considering the water basic, a ratio of 1 : 1, thus bringing out a most interesting relation between this species and native boric acid which has the formula H_3BO_3 . Sussexite may be regarded as an analogous compound in which $\frac{2}{3}$ of the water is replaced by manganese and magnesia, and we may write for its formula $[\frac{2}{3}(Mn, Mg)O + \frac{1}{3}H_2O]_3 \cdot B_2O_3$, or if the water be not considered basic it may be represented by $2(Mn, Mg)O \cdot B_2O_3 + H_2O$.* The former I believe to be the correct view of the composition of the mineral.

In some of its physical and chemical characters sussexite resembles the mineral Szaibelyite from southern Hungary. This mineral is found imbedded in limestone in needle-like crystals, has a hardness of over 3, a density of 3, and is a hydrous borate of magnesia. One variety analyzed by Stromeyer gave the oxygen ratio of $B_2O_3 : MgO : H_2O = 17 : 14.1 : 4$, or of acid to bases including water of 17 : 18.1, or nearly 1 : 1, requiring but a slight change in the determination of water to make this also a mineral analogous in composition to boric acid, with which indeed it is already classified by Prof. Dana in the recent edition of his Mineralogy. Another member of the group is Hydroboracite, a hydrous borate of magnesia and lime. Sussexite is at present a rare mineral, but as it occurs in a vein which is extensively mined, there is every reason to hope that it may become more abundant. Its pyrognostic properties are so very characteristic that it may readily be distinguished from any other mineral which it resembles in physical characters. In addition to fibrous willemite, I have also found chrysotile in fine fibers imbedded in the calcite of Mine Hill; it, however, requires but little familiarity with sussexite to distinguish it at a glance from these species.

* The formula of sussexite is now written $RHBO_3$, $R = Mn$ and Mg . A little zinc was found in a later analysis. — EDITOR.

ON HORTONOLITE,
A NEW MEMBER OF THE CHRYSOLITE GROUP.

By GEORGE J. BRUSH.

WITH MEASUREMENTS AND OBSERVATIONS ON
THE CRYSTALLINE FORM OF THE MINERAL.

By JOHN M. BLAKE.

(From Amer. Jour. Sci., 1869, vol. 48, pp. 17-23.)

SEVERAL years since, Mr. Silas R. Horton called my attention to peculiar dull black crystals from an iron mine at Monroe, in Orange county, New York. On a simple inspection I determined that the crystals represented two species, the one, magnetite, in dodecahedrons; the other a prismatic mineral with somewhat rounded planes, which I took to be pyroxene. At the time I was deterred from making a chemical examination of the latter mineral by the fact that the crystals appeared to be very impure from admixture with magnetite and graphite. I have, however, never been quite satisfied that it was correctly determined, and on recently selecting with care a portion of the substance free from impurities, it proved to gelatinize with acids and to have the pyrognostic characters of an iron chrysolite; and on a more careful examination of the crystals they seemed to be orthorhombic rather than monoclinic, a conclusion confirmed by Mr. Blake's measurements further on.

The mineral has a yellow to dark yellowish green color on the fresh fracture and a vitreous to resinous luster, although the crystals have a black coating and are quite dull. In large masses the mineral is sometimes nearly black, but on the thin edges by transmitted light the color is almost honey-yellow. Minute specks of magnetite are disseminated through the

mass with occasional flakes of graphite. The crystals are sometimes imbedded in calcite, as also associated in cavities with dodecahedral magnetite. They are frequently half an inch long by one quarter broad and one eighth of an inch thick, in some instances much larger. $H. = 6.5$; sp. gr. = 3.91. Before the blowpipe in the closed tube no change takes place; in the open tube and on charcoal the mineral becomes dull and magnetic, and fuses in the platinum forceps at 4; with borax and salt of phosphorus, it reacts for iron and silicic acid, and with soda for manganese. The pulverized mineral forms with chlorhydric acid a gelatinous mass and is almost completely decomposed. Qualitative analysis showed the presence of silica, protoxide of iron, manganese and magnesia, with a minute quantity of potash and a trace of lime. It was found by pulverizing the mineral and suspending the fine powder in water in a beaker and stirring with an electro-magnet of soft iron, that the magnetite could be completely separated from the silicate. Two quantitative analyses made on material thus prepared gave Mr. Wm. G. Mixter—

	I.	II.	Mean.	Oxygen.	
Silica	33.52	33.66	33.59	17.91	
Ferrous oxide	44.28	44.46	44.37	9.85	} 17.56
Manganous oxide	4.72	3.98	4.35	0.98	
Magnesia	16.79	16.56	16.68	6.67	
Lime	trace	trace			
Potash	0.30	0.47	0.39	0.06	
Ignition	0.26	0.26	0.26		
	<u>99.87</u>	<u>99.39</u>	<u>99.64</u>		

These analyses represent two different samplings by means of the electro-magnet, and demonstrate that the method of purification was as perfect as could be desired. In the decomposition by chlorhydric acid it was found that the separated silica contained a very small portion of undecomposed mineral, and this was consequently fused with carbonate of soda to effect a complete decomposition. The iron was separated as basic acetate, redissolved and reprecipitated; the manganese in

the solution was oxidized and separated by bromine, then redissolved and precipitated as phosphate. The magnesia was weighed as pyrophosphate, and the alkali determined by Smith's method. A spectroscopic examination of the concentrated chlorhydric solution showed sodium, potassium, and calcium lines only. A direct determination of the protoxide of iron on mineral selected as free as possible, by aid of the magnifier, from magnetite, gave 42.69 per cent; this, considering the difficulty of selecting absolutely pure material and the fact that the mineral, although almost entirely, is not completely decomposed by acid, shows that the iron is most probably present only as protoxide.

The calculation of the oxygen for the mean of the two analyses gives the ratio of SiO_2 : RO as 17.91: 17.56 or 1:1, in which the relation of the iron to the magnesia is very nearly as 3: 2, and the composition of the mineral is that of an iron-magnesia-manganese chrysolite. In chemical composition this member of the chrysolite family is between hyalosiderite and fayalite, although it differs very materially from both, as will be seen by comparing the analysis with these and allied varieties.

	SiO_2 .	Al_2O_3 .	FeO.	MnO.	MgO.	
1. Hyalosiderite . .	31.63	2.21	29.71	0.48	32.40	} Only traces of other constituents.
2. Dalarne chrysolite .	35.20	1.93	35.55	0.58	26.24	
3. New chrysolite . .	33.59	. . .	44.37	4.35	16.68	
4. Eulysyte chrysolite	29.16	1.56	55.87	8.47	3.23	
5. Fayalite, Fayal . .	28.27	3.45	63.80		tr.	

1. Hyalosiderite, Walchner, Schweigger, Journ. xxxix, 65. 2. Analysis made by Struve, given by Svanberg in Ak. H. Stockholm, 1848, p. 2. 3. This article. 4. A. Erdmann, Min., 278. 5. Rammelsberg, Min. Chem., 435.

The new mineral contains more iron than hyalosiderite, with a correspondingly smaller amount of magnesia, while the opposite is true with fayalite. It more nearly approaches the variety of iron-manganese chrysolite described by Erdmann as occurring near Tunaberg in Sweden, associated with garnet and augite forming a rock which has been named *eulysyte*; from this, however, it differs in containing 13 per cent more

magnesia, and about 16 per cent less iron and manganese, and no lime. The mineral therefore, forms a marked variety of iron-magnesia-manganese chrysolite.

In view of these facts, it is proper to designate this new variety with a special name, and I propose for it the name *Hortonolite*, after Mr. Horton, who first discovered the mineral. If found in quantity, this may prove to be a valuable iron ore, if smelted with more basic or calcareous ores. It is free from undesirable impurities, while it contains a considerable amount of manganese. There is reason to believe that it may occur in sufficient abundance to be of economic importance.

It gives me pleasure to acknowledge my indebtedness to Mr. Horton for kindly supplying me with specimens of this mineral for examination; to Mr. W. G. Mixter, assistant in the Sheffield Laboratory, for aid in the chemical investigation; and to Mr. John M. Blake for his discussion of the crystallographic characters of the mineral which here follows.

Observations on the crystalline form, optical characters, and cleavage of Hortonolite; By JOHN M. BLAKE.

The examination and measurement of crystals of Hortonolite, which were placed in my hands for this object by Prof. Brush, show unmistakably that the mineral belongs to the chrysolite group. A comparison was made with other members of the group, to determine its relation to them. For this purpose, several species were measured, crystals having been placed at my disposal by Prof. Brush. The points compared were the occurrence and proportional development of planes, and to some extent the optical properties and cleavages. This examination is not yet completed, but it being desired that a description of this mineral should be furnished as soon as possible, the results must be given in a form that will require the least explanation.

The observed planes on this variety are :

<i>b</i> , 010	<i>m</i> , 110	<i>k</i> , 021	<i>g</i> , 212
<i>c</i> , 001	<i>d</i> , 101	<i>e</i> , 111	

A deposition of some foreign substance had destroyed the brilliancy of the planes, and this could not be entirely removed so that they would give perfect reflections; and, besides this, some parts of crystals appear to have been originally rounded.

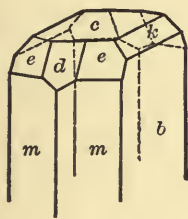


FIGURE 1.

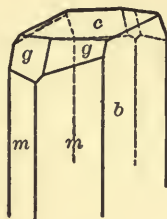


FIGURE 2.

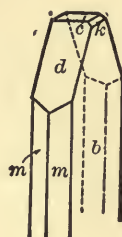


FIGURE 3.

Figure 1 is proportioned from some of the larger crystals. They were partially imbedded, so that but a portion of the planes could be distinguished on any one of them. The intersections with the other planes satisfactorily determined the planes *e* on these particular crystals.

Figure 2 is a common form of the medium-sized crystals. The upper planes on the front side, can be explained as the planes *g*, the directions of their intersections with *m* and an approximate measurement of their inclination on *b* leaving little doubt of their identity with this plane.

Figure 3 represents an occasional form. It is introduced to show the variation in crystals upon the same specimen. Another small crystal had the prismatic planes nearly equal in breadth, and *k* largely developed, while the other terminal planes were rounded.

Notwithstanding this great variation in development, the crystals do not at all resemble those of hyalosiderite in habit; neither do they resemble certain crystals occurring as furnace products, which I have directly compared with them.

NOTE. — Mr. Blake's article has been shortened by omitting the table of measured and calculated angles and the discussion of the optical properties of the mineral. — EDITOR.

ON GAHNITE FROM MINE HILL, FRANKLIN FURNACE, NEW JERSEY.

By GEORGE J. BRUSH.

(From Am. Jour. Sci., 1871, vol. 1, pp. 28-29.)

THE rare species Gahnite has been again found at a new locality in a cross-cut made by the New Jersey Zinc Co. from the valley of the Wallkill river to an opening on the south end of Mine Hill. I collected specimens at this locality in the summer of 1869, and by blowpipe examination at that time determined the mineral to be a zinc spinel.

The mineral differs in its crystalline characters from the specimens of other localities in the frequent occurrence of the cubic plane; in fact the cubic planes are often the largest, so that the crystals are cubes with truncated dodecahedral edges and only small octahedral planes. There are also minute planes of the trapezohedron (211), truncating the edges of the dodecahedron; also others of the trigonal-trisectahedron (331). Besides these there are sometimes two planes between the cubic and the octahedral, which appear, from examination and approximate measurements by Prof. Dana, to belong to the forms (411) and (811). Their surfaces are rounded, and feeble in luster, and generally they are blended in a single curved plane, consequently the measurements are not entirely satisfactory. The inclinations on a cubic plane, obtained by Prof. Dana, are for (411) $160^{\circ} 30'$, for (811), $170^{\circ} 30'$.

The crystals vary in diameter from an eighth of an inch to over an inch and a half; generally, however, they are less than half an inch. The color of the crystals is blackish-green; in thin fragments, olive-green. Hardness = 7.5; specific gravity = 4.89-4.91.

Before the blowpipe the mineral is infusible. With the fluxes it reacts for iron and manganese; and with soda on charcoal it gives a zinc coating.

The analysis in the wet way was made by Mr. Joseph S. Adam of this laboratory. The mineral was decomposed by fusion with bisulphate of potash. The silica was separated in the usual manner, and the iron and alumina thrown down as basic acetates, and this precipitate was examined to insure purity. The iron was determined by titration with permanganate of potash. From the acetic solution the manganese was separated by bromine, and the zinc was thrown down from the filtrate by sulphide of ammonium. The small amount of magnesia was determined as pyrophosphate, care having been first taken to separate the minute traces of it which were found precipitated with the alumina.

Two analyses by J. S. Adam gave :

	I.	II.	Mean.	Oxygen.	Ratio.
Alumina.	49.86	49.70	49.78	23.20	} 25.77
Ferric oxide	8.83	8.33	8.58	2.57	
Zinc oxide	39.39	39.84	39.62	7.82	} 8.12
Manganous oxide	1.20	1.07	1.13	0.25	
Magnesia	0.12	0.14	0.13	0.05	
Silica	0.71	0.42	0.57		
	100.11	99.50	99.81		

This gives the relation of the oxygen of RO and R_2O_3 as 8.12 : 25.77, or 1 : 3.17, which would indicate that a small portion of the iron was present as protoxide. We have but to assume 1.56 per cent of the Fe_2O_3 in the analysis to have existed as FeO in the mineral to reduce the ratio to exactly 1 : 3.

This variety of gahnite shows a larger percentage of zinc than any heretofore analyzed, and is unique in its cubic habit. It is associated with black mica, apatite, calcite, and a brownish variety of chrysolite. A partial analysis of this chrysolite by W. G. Mixer shows it to be a unisilicate of iron, manganese, magnesia, and zinc, probably related to, and possibly identical

with the zinciferous chrysolite described by Prof. W. T. Røp-
per.* A tin-white metallic mineral imbedded in some of the
gahnite crystals proved to have the pyrognostic characters
of leucopyrite.

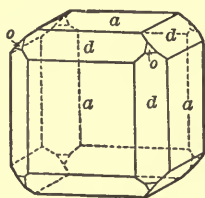


FIGURE 1.

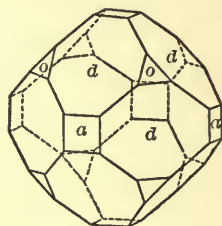


FIGURE 2.

NOTE. — As only a few of the gahnite crystals described
by Professor Brush were found and as they are so unusual in
their development, the liberty has been taken of introducing two
figures of the crystals, drawn by Mr. P. B. Condit of the Sheffield
Laboratory. Figure 2 represents the largest crystal of the suite,
which has a diameter of a little over $1\frac{1}{2}$ inches. — EDITOR.

* Amer. Jour. Sci. (2), vol. 50, p. 35.

ON THE CHEMICAL COMPOSITION OF DURANGITE.

By GEORGE J. BRUSH.

(From Amer. Jour. Sci., 1876, vol. 11, pp. 464-465.)

IN an article * on this rare mineral, published in 1869, I expressed the hope to make further examination of its chemical composition whenever sufficient material could be obtained for this purpose. Several years elapsed before any new discoveries of the mineral in Durango were made. I am again indebted to Mr. Henry G. Hanks of San Francisco for a new supply of the crystals obtained in recent explorations. These crystals are much smaller than those previously examined, being from one to three millimeters in diameter, and they are of a darker shade of color. The former were loose detached crystals, while these are associated with, and in some cases attached to, rolled fragments of crystallized hematite and cassiterite. The density of the small dark colored crystals is 4.07, while that of the purest of the bright colored crystals before described is 3.937. In all other physical characters there is a perfect correspondence between the two varieties.

The chemical examination of the dark colored small crystals has been undertaken, at my request, by my assistant, Mr. George W. Hawes, first to estimate the amount of fluorine in the mineral, which in two determinations he found to be 7.67 and 7.49 per cent, and Mr. Hawes has also placed at my disposal for this article a complete analysis of this variety of the mineral. The fluorine was determined directly by Wöhler's method as modified by Fresenius. To determine the arsenic

* Amer. Jour. Sci. (2), vol. 48, p. 179.

acid, and the bases, the mineral was decomposed by sulphuric acid, and the arsenic weighed as sulphide; the alumina, iron, and manganese obtained in the analysis were carefully examined to ascertain their purity. The soda and lithia were weighted as sulphates and then converted into chlorides and separated by ether and alcohol.

The results of the analysis are as follows:

	I.	II.
Arsenic acid	53.11	...
Alumina	17.19	...
Ferric oxide	9.23	...
Manganic oxide	2.08	...
Soda	13.06	...
Lithia	0.65	...
Fluorine	7.67	7.49
	<u>102.99</u>	

The percentage of fluorine, 7.67, corresponds to 3.23 per cent of oxygen, which being subtracted, the analysis foots up to 99.76. Calculating the percentages of the elements we have the following:

	As.	Al.	Fe.	Mn.	Na.	Li.	Fl.
	34.63	9.18	6.50	1.45	9.69	0.31	7.67
Atomic ratio .	0.462	0.335	0.116	0.026	0.421	0.044	0.404
	0.462	0.477			0.465		0.404

The ratio of As : Al + Fe + Mn : Na + Li : F is very nearly 1 : 1 : 1 : 1; hence the formula may be written Na [AlF]AsO₄, in which a little of the Na and Al are replaced, respectively, by isomorphous Li and Fe and Mn.

This is a confirmation of the conclusion drawn by me from the analysis of the lighter colored crystals described in the original paper.*

The mean of my two analyses gave:

* Loc. cit.

Arsenic acid	54.16
Alumina	20.35
Ferric oxide	4.92
Manganic oxide	1.43
Soda	11.76
Lithia	0.75
Fluorine	undetermined.

The variety examined by Mr. Hawes contains less alumina, and considerably more iron, which accounts for its darker color and slightly higher specific gravity. His results prove the mineral to be an arseniate analogous in chemical composition to amblygonite, as suggested in my previous paper.

NOTE. — Durangite contains a little hydroxyl, as was proved by heating the mineral in a closed tube with freshly ignited lime and obtaining a deposit of water. The amount of water given off is small, and indeed only 0.51 per cent of H_2O is needed in the analysis given above to yield a ratio of $As : F + OH = 1 : 1$. At the time the article on durangite was written fluorine was supposed to replace oxygen, and the isomorphous relation of fluorine and hydroxyl was not known.—EDITOR.

ON A NEW AND REMARKABLE MINERAL LOCALITY AT BRANCHVILLE, IN FAIRFIELD COUNTY, CONNECTICUT; WITH A DESCRIPTION OF SEVERAL NEW SPECIES OCCURRING THERE.—FIRST PAPER.*

By GEORGE J. BRUSH AND EDWARD S. DANA.

(From Am. Jour. Sci., 1878, vol. 16, pp. 33-46.)

Historical Note.

THE new locality of manganesian phosphates, which we shall describe in this and following papers, is situated near the village of Branchville, in the town of Redding, Fairfield County, Connecticut. Its remarkable character will be evident from the statement that we have thus far discovered, among the material which we have obtained from there, no less than six new and well defined species, besides many other known species of more or less rarity.

The locality was first opened some two years since by Mr. A. N. Fillow, upon whose land it is situated, and who made considerable excavations in the search for mica of commercial value. Only a limited quantity of this was obtained, so that the work was finally discontinued and the opening filled up; by which means the ledge was buried under six to eight feet of soil. With most commendable thoughtfulness, however, he laid aside and preserved a large number of specimens which seemed to him to be of some interest. In the latter

* The Branchville Papers are five in number, four of which appeared between the years 1878 and 1880, while the fifth one did not appear until 1890. They are here brought together, but in order to shorten them somewhat it has been necessary to omit descriptions of methods of analysis, tables of measured and calculated angles and some of the less important matter.

—EDITOR.

part of the summer of 1877, Prof. J. D. Dana visited the region and his attention was called by Mr. Fillow to the collection of minerals mentioned, and by him several specimens were brought to New Haven. Later, Rev. John Dickinson, of Redding, the adjoining village, happened to visit the locality and obtained a considerable amount of the minerals, some of which he sent to New Haven for determination. It was not, however, until the early spring of the present year that we were able personally to visit the locality. Appreciating then the unusual interest connected with it, we immediately made arrangements with Mr. Fillow to uncover the ledge and to go forward with the exploration as thoroughly as possible. We have now pushed the matter as far as is practicable for the present, but later in the season we hope to accomplish more. The result of our work has been to place in our hands a large amount of material, in the examination of which we are at present engaged, and we are now ready to make public a portion of the results. In addition to the material we have personally obtained, we have, through the liberality of Mr. Dickinson, come into the possession of a large number of additional specimens collected by himself before our first visits to Branchville. These have been of the greatest service to us in the study of the species occurring at the locality, and we would here express our great appreciation of his generosity. We would also mention our obligations to Mr. Fillow and his brother, who have been most careful in obtaining the best results possible in the explorations of which they have taken charge.

Brief general description.

All the minerals which we have obtained are from a single vein of albitic granite, and the line along which the explorations have been carried does not exceed twenty feet. The general description of the vein and of the minerals which compose it—with the exception of the manganesian phosphates and the immediately associated species—we reserve

for a later paper; we will mention, however, that outside of these we have identified the following species:

Albite, quartz, microcline in large masses, a hydro-mica near damourite having a peculiar concentric spherical structure, spodumene in crystals weighing one to two hundred pounds, cymatolite as a result of the decomposition of spodumene crystals, sometimes nine inches in width, apatite, microlite (sp. gr. = 6), columbite (sp. gr. = 5.6) apatite, garnet, tourmaline and staurolite.

The manganesian phosphates and related minerals occur in nests imbedded in the albite. A single deposit yielded almost all the material obtained, it being probable that what came out as the result of our work was a part of the same body of minerals which Mr. Fillow had blasted into two years before. A second deposit will be mentioned later as having furnished the lithiophilite.

The minerals which form the mass of the first mentioned bed are: — Eosphorite, dickinsonite, triploidite and rhodochrosite. Of these, the first three are new and are described at length in this paper. These four minerals, together with quartz, occur associated in the most intimate manner possible, it being not at all unusual to find all of them in a single hand specimen. This is especially true of the three new minerals: the eosphorite is often found in crystals entirely imbedded in the dickinsonite, and again the finely disseminated plates of dickinsonite give a green color to much of the massive eosphorite. Quartz is also contained in much of the massive eosphorite, thus giving it a very anomalous appearance; it also forms the mass in which the triploidite crystals are imbedded — both these points are spoken of more particularly later. Quartz is also often associated with the rhodochrosite, that mineral being disseminated in crystalline grains through the quartz in which occasional brilliant cubes of pyrite are also imbedded.

In addition to the above minerals, as original constituents of the same deposit, are amblygonite (hebronite), and a phosphate of manganese isomorphous with scorodite which we shall

describe under the name reddingite. As secondary products we have apatite and quartz coating together crystals of eosphorite, vivianite in thin layers and crystals, besides other species, which as yet, owing to lack of sufficient material for examination, we have been unable to determine.

Furthermore, there are a variety of alteration products: each one of the manganesian phosphates yields on alteration a black or purple phosphate of manganese and iron sesquioxides, and the rhodochrosite gives a pseudomorph of hydrated oxides.

The second smaller nest discovered consisted almost exclusively of lithiophilite. Of the previously mentioned minerals rhodochrosite is the only one we have observed with it, and that occurs very sparingly. In addition, however, a peculiar green manganiferous apatite, spodumene, and cymatolite are intimately associated with the lithiophilite, besides the black phosphate produced from its oxidation, and occasional crystals of uraninite and both green and yellow hydrated phosphates of uranium.

From the large amount of black oxidized material, rich in lithia, found with the first deposit it is probable that lithiophilite, or some other similar mineral of the triphylite group, formed one of the original constituents of that mass. In fact it was the discovery of lithia in the black product of decomposition, and its absence in eosphorite, triploidite and dickinsonite, which led us to make further search for the source of this alkali. Fortunately, in the deepest part of our explorations in the vein we struck a small nest which afforded us the fresh unaltered mineral.

We wish here to express our great obligations to Messrs. Samuel L. Penfield and Horace L. Wells of the Sheffield Laboratory, for the excellent analyses which their enthusiastic devotion to the work has enabled us to present in this paper. The carrying through of these analyses has involved in many cases more than usual difficulty, and we appreciate fully to what an extent the value of this article is dependent upon the skill and patient care with which these difficulties have been overcome.

1. EOSPHORITE.

General physical characters. — Eosphorite occurs in prismatic crystals, sometimes of considerable size, which belong to the *orthorhombic system*. They show a nearly perfect macrodiagonal cleavage. It also and more commonly occurs massive, some specimens showing the cleavage finely, but graduating into others which are closely compact. The hardness is 5. For the specific gravity, three perfectly pure rose-colored specimens gave 3.124, 3.134, and 3.145; mean, 3.134. The luster of crystallized specimens is vitreous to sub-resinous, upon cleavage surfaces exceedingly brilliant; of the massive mineral often greasy. The color of the crystals is pink, some having the bright shade common in rose-quartz, while others are paler and have a yellow to gray hue; the smallest crystals are nearly colorless. The massive compact mineral is pale pink, also grayish, bluish, and yellowish-white, and white. Some varieties closely resemble in color and luster green eläolite; the green color, however, is shown by the examination of thin sections under the microscope to be due to finely disseminated scales of dickinsonite. Some varieties again are rendered impure by the presence of quartz through the mass, and they then have a whitish color and granular texture; this subject is expanded in a later paragraph.

The mineral is transparent to translucent. The streak is nearly white, and the fracture uneven to subconchoidal.

Description of crystals. — Specimens of crystallized eosphorite are rare. The most of those obtained seem to have come from a single cavity, the crystals standing free, and projecting to some length. Again they are found completely imbedded, as, for instance, in dickinsonite. These crystals are in general small; but occasionally imperfect crystals of a considerable size are met with, one of these exposes a width of about an inch, and is two inches long; in another, a single plane has a width of nearly two inches. The planes are seldom well polished, and only in rare cases are exact measurements obtainable. This is due in part to the fact that the surfaces

of the crystals are often coated with drusy quartz, and again with minute crystals of apatite, and also because the prismatic planes almost always, and the pyramidal planes very commonly, are finely striated. This striation of the prismatic planes is a marked characteristic and gives rise to rounded barrel-shaped crystals analogous to those observed of tourmaline and many other species.

The crystals are invariably prismatic in habit, and show but one terminated extremity; in this respect they differ from the ordinary childrenite of Tavistock, to which it will be shown they are closely related. The general form is shown in figure 1.

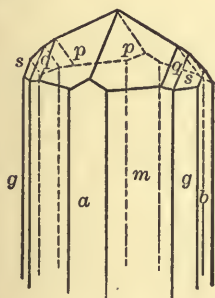


FIGURE 1.
Eosphorite.
Branchville.

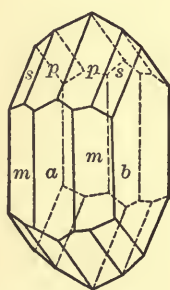


FIGURE 2.
Childrenite.
Hebron, Me.

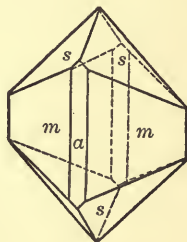


FIGURE 3.
Childrenite.
Tavistock.

The crystallographic measurements and also the optical examination prove that the crystals belong to the ORTHORHOMBIC SYSTEM.

The fundamental angles were obtained from measurements on a small crystal whose pyramidal planes gave excellent reflections. The mean of a considerable number of readings, whose extremes differed by only $1\frac{1}{2}'$, was taken in each case. A goniometer provided with two telescopes was always employed.

These angles are as follows:

$$p \wedge p''' \text{ or } 111 \wedge 1\bar{1}1 = 46^\circ 27' 45''$$

$$p \wedge p' \text{ or } 111 \wedge 111 = 61^\circ 1' 54''$$

From these the following axial ratio is obtained:—

$$a : b : c = 0.77680 : 1 : 0.51501$$

The observed planes are as follows:

<i>a</i> , 100	<i>m</i> , 110	<i>p</i> , 111	<i>s</i> , 121
<i>b</i> , 010	<i>g</i> , 120	<i>q</i> , 232	

Eosphorite is in crystalline form closely homœomorphous with childrenite. Figure 2 represents the common form of the childrenite from Hebron, Maine, as we have found from an examination of the specimens in New Haven. The crystals are sometimes terminated at both extremities as here represented. It is placed in such a position as to correspond with the eosphorite, the pyramid *s* being identical in the two, as are also the prisms. Figure 3 shows a common form of the Tavistock crystals; other crystals have the plane *b* present and resemble figure 2 more closely in habit. The angles given below show the close relation in form between childrenite and eosphorite.

	Eosphorite.	Childrenite. Tavistock (Cooke).	Childrenite. Hebron (Cooke).	Childrenite. Tavistock (Miller).
<i>m</i> $\wedge$ <i>m</i>	75° 41'	75° 24'	74° 20'	75° 46'
<i>s</i> $\wedge$ <i>s'''</i>	81° 18'	81° 20'	80° 38'	82° 8'
<i>s</i> $\wedge$ <i>s'</i>	49° 34'	49° 50'	50° 36'	49° 56'
<i>s</i> $\wedge$ <i>s''</i>	101° 33'	101° 43'	101° 36'	102° 41'

In order to bring the crystals of childrenite into this position the dome *n* of Miller is made the unit prism.

Optical properties.—A careful examination in the stauroscope proved that the three axes of elasticity coincide with the crystalline axes, showing that the crystals are really orthorhombic. The optic axes lie in the macrodiagonal section, or plane of cleavage, the acute bisectrix being normal to the brachypinacoid, and the obtuse bisectrix consequently to the basal plane. The axial angle could not be obtained with very great accuracy, owing to the fact that the best sections left much to be desired in the way of clearness. The measurements gave:

$$\begin{aligned} 2E &= 54^\circ 30' \text{ red rays.} \\ " &= 60^\circ 30' \text{ blue rays.} \end{aligned}$$

The dispersion of the axes is strong, $v > \rho$; the character of the double-refraction is negative.

An examination of a parallelepiped cut with its edges parallel to the three axes of elasticity (crystalline axes) showed a very distinct trichroism. The axial colors are as follows:

For vibrations parallel to *a* (that is *b*) yellowish.

b (that is *a*) deep pink.

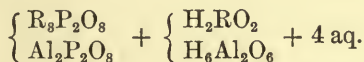
c (that is *c*) faint pink to nearly colorless.

Chemical composition. — The finest of the pink crystals were used for the chemical examination of eosphorite, which was made by Mr. Samuel L. Penfield, assistant in the Sheffield Laboratory.

Two analyses gave:

	I.	II.	Mean.	Relative number of atoms calculated from the mean.		
P ₂ O ₅	31.10	30.99	31.05	0.219	1.00	1
Al ₂ O ₃	21.99	22.40	22.19	0.216	0.99	1
FeO	7.42	7.39	7.40	0.103	0.449	2.05
MnO	23.47	23.56	23.51	0.331		
CaO	0.54	0.54	0.54	0.010		
Na ₂ O	0.33	0.33	0.33	0.005	0.866	3.95
H ₂ O	15.66	15.54	15.60			
	100.51	100.75	100.62			

The ratio P₂O₅ : Al₂O₃ : RO : H₂O = 1 : 1 : 2 : 4 corresponds to the empirical formula R₂Al₂P₂O₁₀ · 4H₂O, which may be written Al₂P₂O₈ + 2H₂RO₂ + 2 aq. The analogy in the composition of eosphorite to that of childrenite suggests, however, that the better way of writing the formula is:



In the formula R corresponds to Mn and Fe with small quantities of Ca and Na₂; the ratio for Mn : Fe + Ca + Na₂ = 3 : 1, and for Mn : Fe = 10 : 3: for the last ratio the above formula requires:

	Eosphorite. Calculated from the formula.	Childrenite, analyzed by Rammelsberg.	Childrenite, analyzed by Church.
P ₂ O ₅	30.93	28.92	30.65
Al ₂ O ₃	22.35	14.44	15.85
FeO	7.24	30.68	{ Fe ₂ O ₃ 3.51 FeO 23.45
MnO	23.80	9.07	7.74
MgO		0.14	1.03
H ₂ O	15.68	16.98	17.10
	100.00	100.23	99.33
	G. = 3.134	G. = 3.247	G. = 3.22

The identity between the crystalline form of eosphorite and that of childrenite has been pointed out in a preceding paragraph, and the analogy between them in chemical composition, and at the same time the wide difference, will be seen from the above. The ratios obtained from the analyses of Rammelsberg and Church for the childrenite from Tavistock and that of eosphorite are as follows:

		P ₂ O ₅ .		R ₂ O ₃ .		RO.		H ₂ O.
Childrenite	{ Rg.	3	:	2	:	8	:	15
	{ Ch.	4	:	3	:	9	:	18
Eosphorite		1	:	1	:	2	:	4 and
Childrenite	{ Rg.	1	:	3 $\frac{1}{3}$	:	5		
	{ Ch.	1	:	3	:	4 $\frac{1}{2}$		
Eosphorite		1	:	3	:	4		

It can hardly be doubted from the above relations and the other facts given that the two species are in fact isomorphous, although the uncertainty that hangs over the composition of childrenite makes it useless to compare the formulas. It is quite possible that, when the composition of childrenite shall be definitely settled, it will be found to be analogous to that given for eosphorite.* It cannot be questioned, however, that the two species, though closely isomorphous, are at the same time perfectly distinct: the physical characters, the habit of

* This prediction has been found to be true. See page 124. — EDITOR.

the crystals, and method of occurrence speak emphatically for this. Chemically, too, they are not to be confounded, although they may be similar compounds; eosphorite is essentially a phosphate of aluminum and *manganese*, and childrenite of aluminum and *iron*.

Pyrognostics.—In the closed tube eosphorite decrepitates, whitens, gives off abundance of neutral water, and the residue turns first black, then gray, and finally liver-brown with a metallic luster, and becomes magnetic. B.B. in the forceps it cracks open, sprouts and whitens, colors the flame pale-green, and fuses at about four to a black magnetic mass. It dissolves completely in the fluxes, giving iron and manganese reactions. It is soluble in nitric and hydrochloric acids.

The name eosphorite is from the Greek *ἠωσφόρος* (a synonym of *φωσφόρος*, whence the name phosphorus), which means *dawn-bearing*, in allusion to the characteristic pink color of the crystallized mineral.

2. TRIPLOIDITE.

Physical characters.—Triplodite occurs in crystalline aggregates which are distinctly parallel-fibrous to columnar in some cases, and in others divergent; and again confusedly fibrous to nearly compact massive. Occasionally individual prismatic crystals are distinct, being separated from one another by the transparent quartz in which they are imbedded and from which they become detached when the mass is broken into small fragments. The isolated crystals have sometimes a length of an inch or more, but it is not possible to detach them except in very small pieces. The conditions are obviously extremely unfavorable to the formation of terminated crystals, but a careful and long-continued search upon a large amount of material was at last rewarded by the discovery of a few more or less perfect specimens. In rare instances the crystals have been observed standing free in small cavities in the massive mineral. The crystals have perfect orthodiagonal cleavage.

The hardness of triplodite is 4.5–5, and the specific gravity 3.697. The luster is vitreous to greasy-adamantine. The

color is yellowish to reddish-brown, in the distinct crystals also topaz- to wine-yellow, and occasionally hyacinth-red. The streak is nearly white. Transparent to translucent. The fracture is subconchoidal.

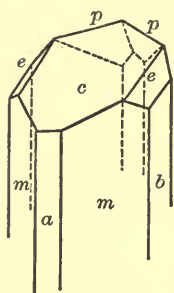


FIGURE 4.

Crystalline form. — Of the few terminated crystals obtained, three only were suitable for measurement and only one of these had the terminations complete. These were extremely small, but the planes were of so high a luster that they gave good reflections, but little inferior to those obtained from the best eosphorite crystals. The planes in the prismatic zone are in the larger crystals so much striated as to admit of no satisfactory measurements. In the crystals selected for

careful measurement the only planes in this zone which could not be used at all were the clinopinacoids, for the others the reflections were reasonably good. The crystals show occasionally false planes, bearing no relation to the axes of the crystal, and which are evidently impressions of portions of adjoining crystals.

These crystals belong to the MONOCLINIC SYSTEM and their habit is shown in Figure 4. The axial ratio was obtained from the following fundamental angles :

$$c \wedge e = 001 \wedge 011 = 54^{\circ} 48'$$

$$a \wedge m = 100 \wedge 110 = 60^{\circ} 27'$$

$$a \wedge c = 100 \wedge 001 = 71^{\circ} 46'$$

These angles are good, though a little less so than those given for eosphorite — the probable error, however, does not exceed $\pm 1'$. The axial ratio is :

$$a : b : c = 1.85715 : 1 : 1.49253; \beta = 71^{\circ} 46'$$

The observed planes are:

$a, 100.$	$c, 001.$	$e, 011.$
$b, 010.$	$m, 110.$	$p, \bar{2}11.$

A comparison of the angles with those given by Brooke and Miller for wagnerite shows that the two species are homœomorphous.

Thus, in the three diametral zones, we have:

Triploidite.	Wagnerite (Miller).
$m \wedge m, 110 \wedge 110, = 120^\circ 54'$	$g \wedge g = 122^\circ 25'$
$c \wedge a, 001 \wedge 100, = 71^\circ 46'$	$c \wedge a = 71^\circ 53'$
$e \wedge e', 011 \wedge 011, = 109^\circ 36'$	$e \wedge e', = 110^\circ 6'$

As the crystal of wagnerite is placed by Miller, the planes g , a , c , and e have the symbols (120), (100), (001), (021) respectively. In the figure given by Miller the prism g (120), corresponding to m (110) of triploidite, has the greatest development; it was made the unit prism by Naumann.

Optical properties.—The only point that could be established in regard to the optical character of triploidite was the position of the axes of elasticity. The crystal used for measurement had the clinopinacoid so far developed that it could be examined directly in a Rosenbusch microscope. It was found that of the two axes which lie in the plane of symmetry, one very nearly coincides with the vertical axis, being inclined behind (see figure 4) $3^\circ-4^\circ$, and the other consequently is almost normal to the orthopinacoid. The position of the optic axes could not be fixed. The crystals show no perceptible absorption phenomena.

Chemical composition.—Triploidite was analyzed by Mr. Penfield. This hydrous phosphate was found to contain iron and manganese, both being in the lowest state of oxidation, with a small amount of lime; it is entirely free from fluorine. The results of two analyses are:

	I.	II.	Mean.		Relative number of atoms calculated from the mean.		
P ₂ O ₅	32.14	32.08	32.11		0.226	1.00	1
FeO	15.07	14.69	14.88	0.207	0.895	3.96	4
MnO	48.35	48.55	48.45	0.682			
CaO	0.36	0.29	0.33	0.006			
H ₂ O	4.01	4.15	4.08		0.226	1.00	1
	99.93	99.76	99.85				

The ratio $P_2O_5 : RO : H_2O = 1 : 4 : 1$ corresponds to the formula $R_4P_2O_9 + H_2O$, or $R_3P_2O_8 + H_2RO_2$, where $R = Mn : Fe = 3 : 1$. This formula requires:

P_2O_5	31.91
FeO	16.18
MnO	47.86
H_2O	4.05
	100.00

Among the other phosphates and arsenates the following seem to be closely related to triploidite in composition:

Libethenite	$Cu_8P_2O_8 + H_2CuO_2$	Orthorhombic.
Olivenite	$Cu_8(P_2, As_2)O_8 + H_2CuO_2$	Orthorhombic.
Lazulite	$Al_2P_2O_8 + H_6Al_2O_8$	Monoclinic.

None of these species has any relation to triploidite in crystalline form. On the other hand, the similarity between the angles of wagnerite and triploidite has already been shown; moreover, the composition of triplite is analogous to that of wagnerite and for these reasons a relation between triplite and triploidite immediately suggests itself. The composition of these minerals is:

Wagnerite	$Mg_3P_2O_8 + MgF_2$.
Triplite	$(Fe, Mn)_3P_2O_8 + (Fe, Mn) F_2$.
Triploidite	$(Mn, Fe)_3P_2O_8 + (Mn, Fe) (OH)_2$.

It should be stated that the perfect transparency and brilliant luster of the crystals analyzed prove beyond all question that the absence of fluorine and the presence of water (determined directly) are not due to any alteration. The fact that all the bases are in the lower state of oxidation would be confirmatory evidence were it needed. The conclusion to which we are led is this — that in the compound triploidite the radical hydroxyl (OH) plays the same part as the element fluorine, the molecule $R(OH)_2$ taking the place of the RF_2 .*

* This is the first mention made of the isomorphous relation of fluorine and the univalent hydroxyl radical, a relation now well established, which has served as a key to the solution of many complex problems in mineral chemistry, several of which will be noted in this volume. — EDITOR.

Pyrognostics.—In the closed tube triploidite gives neutral water, turns black and becomes magnetic. Fuses quietly in the naked lamp flame and B. B. in the forceps, colors the flame green. Dissolves in the fluxes, giving reactions for manganese and iron. Soluble in acids.

An analysis of another specimen of triploidite gave P_2O_5 32.24, FeO 18.65, MnO 42.96, CaO not determined, H_2O 4.09, quartz 1.09. The lime was accidentally lost, but calculating from the amount of phosphoric acid retained by the iron it amounted to 0.90 per cent. The analysis is interesting as showing that the iron and manganese vary in different specimens, the darker colored varieties containing the most iron.

The name *triploidite* given to this species, from *tripelite*, and *εἶδος form*, indicates its resemblance to triplite in physical characters, and its relation in chemical composition.

3. DICKINSONITE.

Physical characters.—Dickinsonite occurs most commonly in crystalline masses, which have a distinctly foliated, almost micaceous, structure. It is also lamellar-radiated and sometimes stellated, the laminae being usually more or less curved. This massive variety forms the gangue in which crystals of eosphorite are often imbedded, and also sometimes triploidite. It moreover occurs in minute scales distributed through the massive eosphorite and giving it a green color, and is sometimes imbedded in the rhodochrosite. Minute tabular crystals are rare; they are observed implanted upon the gangue, and also scattered through the reddingite. In general aspect the mineral resembles some varieties of chlorite though very unlike in its brittleness.

It has perfect basal cleavage. The hardness is 3.5–4, and the specific gravity is 3.338–3.343. Luster vitreous, on the cleavage face somewhat pearly. The color of the purest crystal is oil- to olive-green, in the massive varieties generally grass-green though sometimes quite dark; the streak is nearly white. Transparent to translucent, the crystals being perfectly clear. The laminae are very brittle; fracture uneven.

Crystalline form. — Distinct crystals of dickinsonite are not often found, and owing to the extremely brittle character of the mineral, it is only in very rare cases that they can be

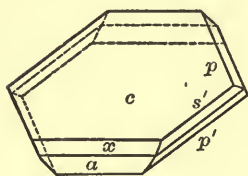


FIGURE 5.

obtained showing more than the basal plane. The crystallographic data which are given here were all obtained from two crystals, which, though extremely small and yielding only approximate angles, yet served to decide all the essential points. Other less perfect crystals gave confirmatory results.

Dickinsonite crystallizes in the MONOCLINIC SYSTEM. The axial ratio and obliquity were obtained from the following angles: —

$$\begin{aligned}\text{Plane angle of the base} &= 120^\circ 0' \\ c \wedge a, \quad 001 \wedge 100 &= 61^\circ 30' \\ c \wedge x, \quad 001 \wedge 301 &= 42^\circ 30'\end{aligned}$$

The axial ratio is: —

$$a : b : c = 1.73205 : 1 : 1.19806; \beta = 61^\circ 30'$$

The observed planes are as follows:

$a, 100$	$c, 001$	$s, 221$
$b, 010$	$p, 111$	$x, 301$

The accompanying figure shows all of these planes except the clinopinacoid, which was only once observed.

It follows from the table of angles, here omitted, that the angle between the base and one of the two pyramids ($c \wedge p = 61^\circ 8'$) differs but little from the angle between the base and the orthopinacoid ($c \wedge a = 61^\circ 30'$); there are thus three planes which have nearly equal inclinations to the base. This fact, which is analogous to that true of the Vesuvian biotite (meroxen), as pointed out by Tschermak, gives to the crystals a marked *rhomboidal* aspect especially as the planes x (301) and s (221) have usually a minor development. As exact measurements were not possible the true relations could hardly be established beyond doubt until recourse was had

to an optical examination. This showed that the cleavage planes are not isotrope as they must be if rhombohedral; on the contrary one plane of vibration is exactly parallel to the edge c/a , and the other normal to it.

The rhombohedral pseudo-symmetry is also shown in the fact that the plane angle of the base differs very little if at all from 120° . The most careful measurements practicable failed to establish any variation. That the angle really is 120° seems, moreover, to be indicated by the fact that on many cleavage laminae triangular markings are visible, which are apparently equilateral, the angles measuring 60° ; other analogous markings have four or five sides but always with angles of 60° or 120° , as near as the measurements can be made.

The above facts show that crystallographically dickinsonite is related to the micas and chlorites, although most unlike them chemically.

The plates of dickinsonite are sometimes striated parallel to the edges c/p , c/p' , and also c/a , corresponding to the triangular markings mentioned, and still more increasing the rhombohedral aspect of the crystals. No twins have been observed, although some very imperfect crystals early suggested their possible occurrence.

The cleavage plates show a marked dichroism, parallel to the edge c/a , the rays being grass-green and much absorbed and normal to this yellow-green. No examination of a section perpendicular to the cleavage was possible, so that the position of the axes of elasticity in the plane of symmetry could not be determined.

Chemical composition. — The following analysis was made by Mr. S. L. Penfield. The purest material available was selected, but it was found impossible to separate it entirely from a little admixed quartz and eosphorite. The small amount of alumina present is assumed to belong to the eosphorite, and the calculations made accordingly. In the table below, column (I) gives the original analysis; (II) gives the amount of each constituent of the impurities to be de-

ducted; (III) gives the remainder after this deduction has been made, and (IV) the final composition after being averaged up to the original amount.

	I.	II. Eosphorite and quartz.	III.	IV.
P ₂ O ₅	37.49	2.13	35.36	39.36
Al ₂ O ₃	1.55	1.55	...	...
FeO	11.64	0.50	11.14	12.40
MnO	24.18	1.63	22.55	25.10
CaO	12.00	...	12.00	13.36
Li ₂ O	0.03	...	0.03	0.03
K ₂ O	0.80	...	0.80	0.89
Na ₂ O	4.71	...	4.71	5.25
H ₂ O	4.55	1.08	3.47	3.86
Quartz	3.30	3.30	...	...
	<u>100.25</u>	<u>10.19</u>	<u>90.06</u>	<u>100.25</u>

The ratio calculated from analysis (IV) is as follows:

P ₂ O ₅ = 0.277	0.277	1.00	4
FeO = 0.172	0.858	3.09	12
MnO = 0.353			
CaO = 0.238			
Li ₂ O = 0.001			
K ₂ O = 0.009			
Na ₂ O = 0.085			
H ₂ O = 0.215	0.215	0.77	3

The ratio P₂O₅ : RO : H₂O = 4 : 12 : 3 corresponds to the formula R₃P₂O₈ + $\frac{3}{4}$ H₂O. If R = Mn : Fe : Ca : Na = 5 : 2 $\frac{1}{2}$: 3 : 1 $\frac{1}{2}$; this formula requires:

P ₂ O ₅ = 40.05
FeO = 12.69
MnO = 25.04
CaO = 11.85
Na ₂ O = 6.56
H ₂ O = <u>3.81</u>
100.00

This corresponds as closely as could be expected with the analysis (IV) given above.

Another analysis by Mr. Penfield on a separate sample of dickinsonite is given below, the lime having been lost is determined by difference. The results are arranged as before: (I) is the original analysis; (II) the amount of quartz and eosphorite present; (III) the result after deducting these, and (IV) the final result calculated again to 100.

	I.	II. Eosphorite and quartz.	III.	IV.
P ₂ O ₅	38.18	2.13	36.05	39.53
Al ₂ O ₃	1.55	1.55	...	...
FeO	11.36	0.50	10.86	11.90
MnO	23.48	1.63	21.85	23.96
CaO	[13.67]	...	[13.67]	[14.98]
Li ₂ O	0.22	...	0.22	0.24
K ₂ O	0.67	...	0.67	0.73
Na ₂ O	4.36	...	4.36	4.78
H ₂ O	4.62	1.08	3.54	3.88
Quartz	1.89	1.89	...	...
	<u>100.00</u>	<u>8.78</u>	<u>91.22</u>	<u>100.00</u>

Pyrognostics. — In the closed tube gives water, the first portions of which react neutral to test paper, but the last portions are faintly acid. The residue is magnetic. Fuses in the naked lamp flame, and B. B. in the forceps colors the flame at first pale green, then greenish yellow. Dissolves in fluxes and affords reactions for iron and manganese. Soluble in acids.

There is no known phosphate, so far as we are aware, which bears any relation to dickinsonite in crystallographic character, and in chemical composition it seems also to be without any very near relatives.

We have named this most interesting mineral *dickinsonite* in honor of the Rev. John Dickinson of Redding, Conn., our obligations to whom we have already acknowledged.

4. LITHIOPHILITE.

The occurrence of this mineral in the deepest explorations made has already been mentioned. It is found imbedded in albite in irregular rounded masses one to three inches in diameter and coated with a black mineral, the result of its own oxidation; some of these masses have only a small core of unaltered mineral.

Physical characters.—No crystals of lithiophilite were found, although some of the imbedded masses have in external form a somewhat crystalline aspect. There are three distinct cleavages: one quite perfect, always observable whenever the mineral is broken; a second nearly perfect at right angles to the first; and a third interrupted, which is prismatic, having an angle of 128° – 130° , and inclined at right angles to the first named cleavage, and 115° – 116° to the second. The similarity in composition between this species and triphylite makes it possible to identify these three cleavages with those shown by Tschermak to belong to the latter mineral: the most perfect cleavage is basal, the second nearly perfect is brachydiagonal, and the third interrupted cleavage is prismatic ($m \wedge m = 133^{\circ}$ in triphylite, Tschermak).

The hardness is about 4.5; and the specific gravity, in two trials, 3.424, and 3.432. The color of the unaltered mineral is generally bright salmon-color, occasionally honey-yellow, — varying to yellowish-brown and in rare instances to umber-brown; this darker color is probably due to incipient alteration. It has a vitreous to resinous luster, and is generally translucent, though small cleavage fragments are occasionally perfectly transparent. Fracture uneven to subconchoidal.

Optical properties.—The optic axes in lithiophilite lie in the basal section or plane of most perfect cleavage, the acute bisectrix being normal to the brachypinacoid. The axial angle is very large, the axes being partially visible in the extreme border of the field in the polariscope. The angle could not be measured satisfactorily except in oil ($n = 1.47$); the results of the measurements are as follows:

$2H\alpha = 74^{\circ} 45'$ for red rays.

$2H\alpha = 79^{\circ} 30'$ for blue rays.

The dispersion of the axes is strong, $v > \rho$. The character of the double refraction is positive. The three axial colors are quite distinct, as follows:

For vibrations parallel to *a* (that is *a*) deep pink.

b (that is *c*) pale greenish yellow.

c (that is *b*) faint pink.

Chemical composition.—The following analyses are by Mr. Horace L. Wells.

	I.	II.	Mean.	Quantivalents.		Ratio.	
P ₂ O ₅	44.83	44.51	44.67	0.314	0.314	1.00	1
MnO	40.80	40.91	40.86	0.576	} 0.632	2.01	2
FeO	3.99	4.04	4.02	0.056			
Li ₂ O	8.72	8.55	8.63	0.288	} 0.290	0.93	1
Na ₂ O	0.13	0.16	0.14	0.002			
H ₂ O	0.77	0.87	0.82				
SiO ₂	0.63	0.66	0.64				
	99.87	99.70	99.78				

The ratio $P_2O_5 : \overset{II}{R}O : \overset{I}{R}_2O = 1 : 2 : 1$ proves lithiophilite to be a normal phosphate analogous in composition to triphylite. Its formula is $LiMnPO_4$ or $Li_3PO_4 + Mn_3P_2O_8$. This formula requires:

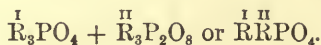
P ₂ O ₅	45.22
MnO	45.22
Li ₂ O	9.56
	100.00

The mineral lithiophilite is consequently a manganese member of the triphylite group. Mr. Penfield has previously shown that the true formula of triphylite, hitherto doubtful, is $\overset{I}{R}_3PO_4 + \overset{II}{R}_3P_2O_8^*$, where $\overset{I}{R} = Li$, and $\overset{II}{R} = Fe$ mostly, also Mn. His conclusions are confirmed by the results of Mr. Wells' analysis of lithiophilite.

Rammelsberg found (as a mean of four analyses) in the Bodenmais mineral 39.97 per cent FeO, and 9.80 per cent MnO.

* Amer. Jour. Sci., 1877, vol. 13, p. 425.

Mr. Penfield, in his analysis of the Grafton, New Hampshire, obtained 26.09 per cent of FeO and 18.17 per cent MnO. The altered triphylite from Norwich, Mass., also contains a considerable amount of manganese, but as manganese-sesquioxide (22.59–24.70 per cent); the unaltered mineral has never been analyzed. These facts go to show that between the true triphylite (the *iron*-lithium phosphate) and the lithiophilite (the *manganese*-lithium phosphate) a number of different compounds exist, containing varying amounts of iron and manganese, as is true in many other analogous cases of isomorphous groups of compounds. It is probable, however, that to all varieties of the two minerals belongs the general formula:



Pyrognostics. — In the closed tube gives trace of moisture, turns dark brown and fuses, but does not become magnetic. Fuses in the naked lamp-flame, and B. B., gives an intense lithia-red flame streaked with pale green on the lower edge. Dissolves in the fluxes giving in O. F. a deep amethystine bead, and in R. F. a faint reaction for iron. Soluble in acids.

The name lithiophilite, from *lithium* and *φίλος*, *friend*; may properly be given to this species, as it contains a very high percentage of lithia.

5. REDDINGITE.

Physical characters. — Reddingite occurs sparingly in minute octahedral crystals, belonging to the *orthorhombic system*. It is also found more generally massive with granular structure; it is associated with dickinsonite, and sometimes with triploidite. As compared with the other species which have been described it is a decidedly rare mineral. The massive mineral shows a distinct cleavage in one plane, the crystallographic direction of which could not be ascertained in the crystals owing to their small size.

The hardness is 3–3.5; and the specific gravity for the mineral analyzed, containing 12 per cent quartz is 3.04; this gives on

calculation for the pure mineral 3.102. The luster is vitreous to sub-resinous: the color of the perfectly unaltered mineral is pale rose-pink to yellowish-white, sometimes with a tinge of brown; crystals are occasionally coated dark reddish-brown from surface alteration; the streak is white. Transparent to translucent; fracture uneven; brittle.

Crystalline form.—The crystals of reddingite are rare and occur only in cavities in the massive mineral. They have uniformly an octahedral habit; sometimes only the unit pyramid is present, and in other cases a second macrodiagonal pyramid, with the brachy-pinacoid, as shown in the accompanying figure. The crystals belong to the ORTHORHOMBIC SYSTEM. The fundamental angles are as follows:

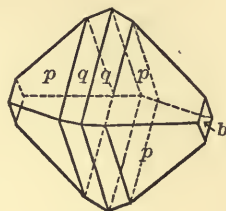


FIGURE 6.

$$\begin{aligned} p \wedge p', \quad 111 \wedge I11 &= 76^\circ 50' \\ p \wedge p'', \quad 111 \wedge II1 &= 110^\circ 43' \end{aligned}$$

These angles are only tolerably exact, the probable error being as high as $\pm 5'$. The axial ratio calculated from the above angles is:

$$a : b : c = 0.8678 : 1 : 0.9485$$

The observed planes are:

$$b, 010 \qquad p, 111 \qquad q, 212$$

Reddingite is closely isomorphous with scorodite and strengite; the corresponding pyramidal angles for the three species are as follows:

Reddingite.	Scorodite. (vom Rath).	Strengite. (Nies).
$111 \wedge I11 = 76^\circ 50'$	$77^\circ 8'$	$78^\circ 22'$
$111 \wedge I11 = 65^\circ 16'$	$65^\circ 20'$	$64^\circ 24'$
$111 \wedge II1 = 110^\circ 43'$	$111^\circ 6'$	$111^\circ 30'$

The axial ratios of the three species are as follows:

	a.		b.		c.
Reddingite	0.8678	:	1	:	0.9485
Scorodite (vom Rath)	0.8658	:	1	:	0.9541
Strengite (Nies) . .	0.8652	:	1	:	0.9823

The relations of the three species in chemical composition are spoken of in a later paragraph.

Chemical composition.—The best available material was used in the analyses by Mr. Horace L. Wells; it was free from every impurity with the exception of the quartz, which was so intimately intermixed that separation was impossible. The presence of the quartz, however, did not interfere in the least with the accuracy of the composition finally deduced. The water was determined directly.

Two analyses gave:

	I.	II.	Mean.
Quartz	12.09	12.07	12.08
P ₂ O ₅	30.17	30.56	30.37
MnO	40.85	40.58	40.71
FeO	4.88	4.70	4.79
Na ₂ O (trace Li ₂ O)	0.32	0.23	0.27
CaO	0.70	0.64	0.68
H ₂ O	11.70	11.33	11.51
	<u>100.71</u>	<u>100.11</u>	<u>100.41</u>

Excluding quartz, the mean of the two above analyses gives:

P ₂ O ₅	34.52	0.243	0.243	1.00
MnO	46.29	0.652	0.746	3.07
FeO	5.43	0.075		
Na ₂ O (tr. Li ₂ O)	0.31	0.005		
CaO	0.78	0.014		
H ₂ O	<u>13.08</u>	0.727	0.727	3.00
	100.41			

The ratio P₂O₅ : RO : H₂O = 1 : 3 : 3, corresponds to the formula Mn₃P₂O₈ + 3 aq., which requires the following percentage composition:

$$\begin{array}{r}
 \text{P}_2\text{O}_5 = 34.72 \\
 \text{MnO} = 52.08 \\
 \text{H}_2\text{O} = \underline{13.20} \\
 100.00
 \end{array}$$

It is interesting to note here that the same formula was deduced by M. Debray* for an artificial salt which he obtained in brilliant crystalline grains by boiling a solution of phosphoric acid in excess with pure manganese carbonate. He gives, however, no description of the form of the crystals obtained.

The close correspondence of reddingite with scorodite and strengite has already been pointed out; chemically the relation is not so close, for the manganese is all in the lowest state of oxidation and only three molecules of water are present. The formulas for the three minerals are as follows:

Reddingite	$\text{Mn}_3\text{P}_2\text{O}_8 + 3 \text{ aq.}$
Scorodite	$\text{Fe}_2\text{As}_2\text{O}_8 + 4 \text{ aq.}$
Strengite	$\text{Fe}_2\text{P}_2\text{O}_8 + 4 \text{ aq.}$

Pyrognostics. — On heating in the closed tube, whitens at first, then turns yellow and finally brown, but does not become magnetic. In the forceps fuses in the naked lamp flame ($F = 2$). B. B. colors the flame pale green and fuses easily to a blackish-brown non-magnetic globule. Dissolves in the fluxes and reacts for manganese and iron. Soluble in hydrochloric and nitric acids.

Reddingite is named from the town in which the locality is situated. It was the last of the above species to be discovered, and we were led to make an especial search for it by finding black octahedrons implanted upon one specimen which were obviously pseudomorphs and which could not be referred to any known species. Another specimen exhibited pseudomorphs of the same species, but where the alteration was not so far advanced.

* Annales de Chimie et de Physique, III, lxi, 433, 1861.

SECOND BRANCHVILLE PAPER.

BY GEORGE J. BRUSH AND EDWARD S. DANA.

(From Amer. Jour. Sci., 1879, vol. 17, pp. 359-368).

IN the preceding pages an account has been given of the discovery of a new mineral locality at Branchville, Fairfield County, Connecticut, including descriptions of five new minerals, all manganesian phosphates, occurring there. During the autumn following the publication of our article we pushed forward our explorations at the locality with as much vigor as possible, and with tolerable success. We were fortunate in finding a new and independent deposit of the phosphates, and obtained from it a considerable quantity of eosphorite, lithiophilite and a little triploidite, and with them some other species of interest, among which we may mention a series of uranium compounds. The detailed description of these discoveries we shall defer until a third paper. In the present paper we propose to give the descriptions of the two additional new species we have identified; one of these we mentioned in our last paper under the name of *fairfieldite*. We add also the results of a new analysis of reddingite, and some further facts in regard to lithiophilite. Both of the new species came from the original material, removed by Mr. Fillow, when the locality was first opened.

6. FAIRFIELDITE.

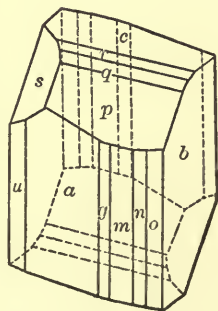
General physical characters.—Fairfieldite occurs usually in massive crystalline aggregates; also rarely in distinct crystals. The structure is foliated to lamellar, some varieties closely resembling selenite; also occasionally in radiating masses consisting of curved foliated or fibrous aggregations; these radiated forms are not unlike stilbite.

The hardness is 3.5, and the specific gravity 3.15. The luster is pearly to sub-adamantine; on the surface of perfect cleavage (*b*) it is highly brilliant. The color is white to pale straw-yellow; the streak is white. Transparent. Brittle.

Two rather distinct varieties have been observed: the first (A) occurs filling cavities in the reddingite, and covering the distinct crystals of this mineral. It is uniformly clear and transparent, and is highly lustrous, showing entire absence of even incipient alteration. It is generally foliated to lamellar, although sometimes of a somewhat radiated structure. The second variety (B) occurs in masses of considerable size interpenetrated rather irregularly with quartz, and quite uniformly run through with thin seams and lines of a black manganesian mineral of not very clearly defined character. This mineral is granular in texture, lustrous, is difficultly fusible, and consists for the most part of the hydrated oxides of manganese and iron; but contains also phosphoric acid and traces of lime.

This second variety of fairfieldite is often friable to the touch and lacks something of the brilliant luster of the first variety. It also shows greater difference of structure, passing from the distinct crystals to the massive and radiated form. The identity of these two kinds is shown by the analyses given below. Fairfieldite also occurs in small particles in fillowite (described beyond), and in masses of some size immediately associated with eosphorite, triploidite, and dickinsonite.

Crystalline form. — Indistinct crystals of fairfieldite occur occasionally in cavities in the massive mineral. They are usually composite in character, made up of many individual crystals, interpenetrating each other, and in only an approximately parallel position. On the most favorable crystals the form could be clearly made out, but exact measurements were quite impossible; this is the more to be regretted



as the number of variable elements is so large. The cleavage parallel to b (010) is highly perfect; that parallel to a (100) somewhat less so.

The crystals belong to the *Triclinic System*, and the general habit is shown in the adjoining figure. The following supplement angles were accepted as the basis of the calculations.

$$\begin{array}{ll} a \wedge c & 100 \wedge 001 = 88^\circ \\ a \wedge b & 100 \wedge 010 = 102^\circ \\ a \wedge p & 100 \wedge 111 = 56^\circ 30' \\ c \wedge p & 001 \wedge 111 = 78^\circ 30' \end{array}$$

From these angles, the lengths and mutual inclinations of the axes were calculated, as follows:

$$a : b : c = 0.2797 : 1 : 0.1976; \alpha = 102^\circ 9', \beta = 94^\circ 33', \\ \gamma = 77^\circ 20'.$$

The observed planes are as follows:

a , 100	p , 111	s , 141	n , 230
b , 010	q , 112	g , 320	o , 120
c , 001	r , 113	m , 110	μ , 110

In one case an apparent penetration-twin was observed, the two crystals crossing one another so that the planes b and a of the one were parallel respectively to the planes a and b of the other. If this coincidence were perfect (exact measurement was out of the question) and the crystal were really a twin the twinning-plane must make with a (100) an angle of either 51° (toward 010) or 39° (toward $0\bar{1}0$). This condition is equally well satisfied by the plane 270 ($100 \wedge 270 = 51^\circ 4'$), or by $2\bar{7}0$ ($100 \wedge 2\bar{7}0 = 39^\circ 3'$.) As this supposed twinning-plane has so complex a relation to the other planes of the crystal, it is probable that this coincidence is only accidental.

Optical properties.—Minute fragments of fairfieldite parallel to the two cleavage planes were examined in the stauroscope, with the following results:—The planes of light-vibration intersect the cleavage plane a (100) in lines which make angles of 40° and 50° , respectively, with the edge $a \mid b$. One optical

axis was visible on the edge of the field in converging light, obviously lying in the vibration-plane making an angle of 50° with the obtuse edge named, and toward that edge.

The cleavage plane parallel to b (010) is intersected by the vibration planes in lines making angles of 10° and 80° respectively with the edge $b \mid a$. In this case also an optical axis (the second) is distinctly visible on the outer limit of the field. This serves to fix approximately the position of the bisectrix. As the cleavage fragments examined were less than $\frac{1}{2}$ mm. in size, any further examination was impossible.

Chemical composition.—The two varieties of fairfieldite have been analyzed by Mr. S. L. Penfield, with the following results:

	A.	B.
P ₂ O ₅	38.39	39.62
FeO	5.62	7.00
MnO	15.55	12.40
CaO	28.85	30.76
Na ₂ O	0.73	0.30
K ₂ O	0.13	...
H ₂ O	9.98	9.67
Quartz	1.31	0.55
	<u>100.56</u>	<u>100.30</u>

The ratios of the oxides calculated from these analyses are as follows:

		A.			B.	
P ₂ O ₅	0.270	0.270	1.00	0.279	0.279	1.00
FeO	0.078	0.825	3.06	0.097	0.826	2.96
MnO	0.219			0.175		
CaO	0.515			0.549		
Na ₂ O	0.012			0.005		
K ₂ O	0.001	0.554	2.05	...	0.537	1.93
H ₂ O	0.554			0.537		

The ratio P₂O₅ : RO : H₂O = 1 : 3 : 2 answers to the formula R₃P₂O₈ + 2 aq. If here R = Ca : Mn + Fe = 2 : 1 and the ratio of Mn : Fe be also 2 : 1, the formula requires:

P ₂ O ₅	39.30
FeO	6.64
MnO	13.10
CaO	30.99
H ₂ O	9.97
	100.00

The fact that the second variety was friable and somewhat deficient in luster suggested an incipient alteration, but the analysis did not confirm this idea. The larger amount of lime afforded in the analysis of this kind is possibly due to admixture of a little apatite, which is often observed with it, and the larger proportion of iron may be due to the fact that this variety could not be entirely freed from the black oxide interpenetrating it.

Pyrognostics. — In the closed tube fairfieldite gives off neutral water, and the assay turns first yellow, then dark brown, and becomes magnetic. In the forceps glows, blackens, and fuses quietly at about 4.5 to a dark yellowish-brown mass, coloring the flame pale green, with faint reddish-yellow streaks on the upper edge. Soluble in the fluxes giving reactions for iron and manganese. Fairfieldite is soluble in nitric and hydrochloric acids.

Fairfieldite is named from the county in which the locality occurs.

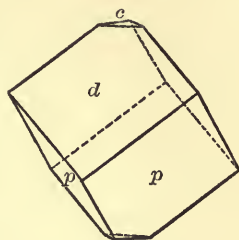
7. FILLOWITE.

General physical characters. — Fillowite occurs in granular crystalline masses. By fracture the crystalline grains can be usually separated with ease; they show in most cases merely striated planes of contact, having no crystallographic significance; occasionally, however, isolated but brilliant crystalline planes are observed and rarely a nearly complete crystal. The masses are not infrequently penetrated by distinct prismatic crystals of triploidite; and sometimes they enclose particles of fairfieldite. The outer surfaces are very often coated with a silvery-white radiated mineral, but in so sparing quantities that we have been thus far unable to determine definitely its character. Reddingite is very commonly associated with

fillowite, and in many cases it is not easy to distinguish the two minerals.

The hardness is 4.5, and the specific gravity in two trials 3.41 and 3.45. The luster is sub-resinous to greasy. The color generally wax-yellow, also yellowish to reddish-brown with a red or green tinge, and rarely almost colorless. Streak white. Transparent to translucent; fracture uneven; brittle.

Crystalline form. — The crystals of fillowite, whose occurrence has already been mentioned, have a marked rhombohedral aspect. As shown in the figure the three planes, whose several inclinations are almost identical, have their common solid angle replaced by a nearly equilateral triangle. The measurements, however, point to a monoclinic form, and that this is the true explanation is proved by the optical examination. The cleavage is basal, nearly perfect.



The angles accepted as the basis for calculation are as follows:

$$\begin{array}{ll} c \wedge p & 001 \wedge 111 = 58^\circ 40' \\ c \wedge d & 001 \wedge 201 = 58^\circ 31' \\ p \wedge p & 111 \wedge 1\bar{1}1 = 95^\circ 23' \end{array}$$

Calculated from these the elements of the crystal are:

$$a : b : c = 1.7303 : 1 : 1.4190; \beta = 89^\circ 51'$$

The position taken for the crystal is that which exhibits most strikingly its close approximation to the rhombohedral form.

The observed planes have already been given; they are:

$$c, 001 \qquad d, 201 \qquad p, 111$$

Optical properties. — It was found possible to examine small cleavage fragments of fillowite according to the usual methods, and the results served to settle the question of the system, which the measured angles might have left undecided. One vibration-plane intersects the basal plane (cleavage) parallel

to the edge $c \mid d$ and the other is normal to it. Moreover the two optic axes are visible when the Rosenbusch microscope is employed; it was impossible to decide, however, in which plane they lay, since the only sections transparent enough for this examination were destitute of the other crystalline planes.

Chemical properties. — The analyses of fillowite by Mr. S. L. Penfield afforded the following results:

	I.	II.	Mean.		Ratios.	
P ₂ O ₅	39.06	39.15	39.10	0.275	2.75	1.00
FeO	9.48	9.18	9.33	0.129	8.51	3.09
MnO	39.48	39.36	39.42	0.555		
CaO	undet.	4.08	4.08	0.073		
Na ₂ O	5.65	5.84	5.74	0.092		
Li ₂ O	0.07	0.04	0.06	0.002		
H ₂ O	1.75	1.56	1.66	0.092	0.92	0.33
Quartz	0.86	0.90	0.88			
		100.11	100.27			

The ratio P₂O₅ : RO : H₂O = 1 : 3 : $\frac{1}{3}$, corresponds to the formula 3R₃P₂O₈ + H₂O. If in this formula R = Mn : Fe : Ca : Na₂ = 6 : 1 : 1 : 1, the calculated percentages are:

P ₂ O ₅	40.19
FeO	6.80
MnO	40.19
CaO	5.28
Na ₂ O	5.84
H ₂ O	1.70
	100.00

The very small amount of water present suggests the question as to whether it is really an original constituent of the mineral. This question we have been unable to decide positively; we can only add that, of a large number of specimens examined, all, even the most transparent, showed its presence. Moreover, if the water be not essential, the composition of the mineral would be somewhat analogous to triphylite, containing sodium instead of lithium, and the want of correspondence in crystalline form does not favor this idea.

Pyrognostics. — In the closed tube fillowite yields a small amount of water which reacts neutral. B. B. in the forceps

colors the flame momentarily pale green, then intensely yellow and fuses with intumescence to a black feebly magnetic globule. Fusibility, 1.5. With the fluxes reacts for iron and manganese. Soluble in nitric and hydrochloric acids.

We have named this, the *seventh* new manganesian phosphate from this locality, after Mr. A. N. Fallow, of Branchville, Conn., our obligations to whom we have already mentioned in our former paper.

REDDINGITE.

In our preceding paper we described the new mineral reddingite, and showed that in the habit of its octahedral crystals and in their angles it was closely homœomorphous with scorodite and strengite. In composition, however, it was shown that there was a variation, as follows:—

Scorodite	$\text{Fe}_2\text{As}_2\text{O}_8 + 4 \text{ aq.}$
Strengite	$\text{Fe}_2\text{P}_2\text{O}_8 + 4 \text{ aq.}$
Reddingite	$\text{Mn}_3\text{P}_2\text{O}_8 + 3 \text{ aq.}$

It is thus seen that reddingite differs from the other species in that the metal is in the protoxide condition, and again since there are only three equivalents of water present. In order to establish beyond all question that this difference was a real one, we have had a second analysis made. The material was selected from another specimen, and, as before, was obtained free from all impurities except quartz.

The analyses, made by Mr. Horace L. Wells, are given below (A) as also that by him (B) published in our preceding paper:

	I.	II.	A. Excluding quartz.	B.
P_2O_5	33.58	. . .	35.16	34.52
FeO	7.54	. . .	7.89	5.43
MnO	41.28	. . .	43.22	46.29
CaO	0.67	. . .	0.71	0.78
Na_2O	trace	. . .	. . .	0.31
H_2O	11.72	11.72	12.27	13.08
Quartz	4.46	4.39	. . .	. . .
	<u>99.25</u>		<u>99.25</u>	<u>100.41</u>

The new analysis leads to the formula $\text{Mn}_3\text{P}_2\text{O}_8 + 3 \text{ aq.}$, or the same as that obtained before. The only marked difference between the two results is one which we have found to characterize all the species of the locality, that is, a little variation in the relative amounts of iron and manganese. That the manganese is really in the protoxide condition cannot be questioned for a moment.

Recapitulation.

It seems of some interest to place together the seven new species which the locality has afforded us. We shall hope, at some future time, to offer some remarks in regard to their mutual relations; we can only say here that there is in the facts observed nothing to suggest that any one of the species is a secondary mineral or a product of alteration; all seem to be original minerals of the vein. We have found single hand-specimens which exhibit all of the first four minerals together.

1. EOSPHORITE.		Orthorhombic.
$\text{R}_2\text{Al}_2\text{P}_2\text{O}_{10} \cdot 4\text{H}_2\text{O}$,	or	$\text{Al}_2\text{P}_2\text{O}_8 + 2\text{H}_2(\text{Mn, Fe})\text{O}_2 + 2 \text{ aq.}$
2. TRIPLOIDITE.		Monoclinic.
$\text{R}_4\text{P}_2\text{O}_9 \cdot \text{H}_2\text{O}$	or	$(\text{Mn, Fe})_3\text{P}_2\text{O}_8 + (\text{Mn, Fe})(\text{OH})_2$.
3. DICKINSONITE.		Monoclinic.
$4(\text{R}_3\text{P}_2\text{O}_8) \cdot 3\text{H}_2\text{O}$	or	$4(\text{Mn, Fe, Ca, Na})_3\text{P}_2\text{O}_8 + 3 \text{ aq.}$
4. LITHIOPHILITE.		Orthorhombic.
LiMnPO_4	or	$\text{Li}_3\text{PO}_4 + \text{Mn}_3\text{P}_2\text{O}_8$.
5. REDDINGITE.		Orthorhombic.
$\text{R}_3\text{P}_2\text{O}_8 \cdot 3\text{H}_2\text{O}$	or	$(\text{Mn, Fe})_3\text{P}_2\text{O}_8 + 3 \text{ aq.}$
6. FAIRFIELDITE.		Triclinic.
$\text{R}_3\text{P}_2\text{O}_8 \cdot 2\text{H}_2\text{O}$	or	$(\text{Ca, Mn, Fe})_3\text{P}_2\text{O}_8 + 2 \text{ aq.}$
7. FILLOWITE.		Monoclinic.
$3(\text{R}_3\text{P}_2\text{O}_8) \cdot \text{H}_2\text{O}$	or	$3(\text{Mn, Fe, Ca, Na})_3\text{P}_2\text{O}_8 + \text{aq.}$

THIRD BRANCHVILLE PAPER.

BY GEORGE J. BRUSH AND EDWARD S. DANA.

(From Amer. Jour. Sci., 1879, vol. 18, pp. 45-50.)

IN the present paper we purpose giving an account of the results of our exploration of the Branchville locality during the past year, so far as they relate to the manganesian phosphates. In our preceding papers we have confined ourselves almost exclusively to the original body of phosphates exploited by Mr. Fillow; we having mentioned in addition only the occurrence of a single small deposit of lithiophilite. When we first opened the locality, our hope was to rediscover the body of minerals from which the specimens preserved by Mr. Fillow had been obtained. Our success in this was quite indifferent; we did, indeed, find the spot aimed at, and took from it a small quantity of the minerals in which we were interested, but it was soon clear that this deposit was exhausted, and we must look farther for other and independent ones. Having but little to guide us in our explorations, we extended them quite widely in the seemingly most probable directions and expended, in time and money, more than our final success would, perhaps, have warranted. We discovered, however, many interesting points in regard to the minerals occurring in the vein as a whole, which we intend to describe in another paper.

Lithiophilite. — As regards the phosphates, the mineral lithiophilite has been proved to exist in considerable quantities. It occurs usually not in large deposits, but in single, isolated masses, from the size of a cherry to others several inches across. The method of occurrence is quite uniform. The masses are irregular in shape, sometimes rounded, sometimes angular, and interpenetrating the associated minerals in the most intimate manner. These associated minerals are more

particularly feldspar, usually albite, and spodumene. The latter mineral is very generally altered, and the various products of its alteration, of which cymatolite is the most common, we shall describe in another place. The lithiophilite, however, though often coated black externally, is otherwise quite free from alteration; the only exception to this was in the case of that first discovered, which was situated near the surface of the ledge and was much oxidized. It will be remembered that, in what we have alluded to as the original deposits of phosphates, the lithiophilite occurred very sparingly and only as an occasional nucleus of masses of the abundant black mineral, the product of its alteration. This is described in our preceding paper, and analyses of these oxidation products are there given.

The lithiophilite of which we are now speaking has, in almost all cases, the salmon color of that first described. In one specimen the amount of iron was determined by Mr. Penfield and found to be but 3.56 per cent. The lithiophilite sometimes contains imbedded rhodochrosite. Other constantly associated minerals are: apatite, garnet, uraninite in brilliant black octahedrons, uranium phosphates, and a silicate containing uranium, near cyrtolite, all of which will be described later.

The lithiophilite was the only mineral of the manganesian phosphate group found in these small isolated deposits. A larger mass finally reached, however, gave us another variety of this mineral, and also several of the other species. This mass was of so peculiar a nature as to deserve a somewhat minute description. It afforded first, for the most part, only lithiophilite, but of a different color from that before obtained, and of slightly different composition as shown by the analysis given beyond. Closely associated with the lithiophilite was a considerable amount of a granular, often also cellular, manganesian carbonate, rhodochrosite. This was quite impure, often containing interpenetrated crystals of white apatite, and also quartz. With the lithiophilite and rhodochrosite, are small quantities of eosphorite and triploidite and traces

of dickinsonite; we were interested in finding hand specimens, showing all these phosphates together, entirely free from alteration, and in such a juxtaposition as to seem to prove a contemporaneous origin. Crystallized out in cavities in the rhodochrosite and again in thin seams of strings through it was a reddish-brown mineral which proved to be chabazite.

Immediately connected with the minerals described was a large mass of a green chloritic mineral, of which we took out some hundred pounds. Its especial interest lay in the intimate manner in which it was associated with the minerals just mentioned. This is particularly true of the eosphorite, which was scattered irregularly through it in nodules of great variety in shape and size. These nodules have often a banded coating of a firm whitish substance, which may have been derived from the alteration of the original mineral, and which entirely conceals the eosphorite within.

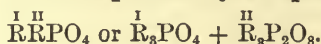
Having given this general description of the method of occurrence of these minerals, we will now proceed to describe some of them more minutely.

LITHIOPHILITE.

We have already stated that almost all of the lithiophilite discovered was similar in its salmon and salmon-pink color, and, as far as tested, in composition, to that described in our first paper; in other words, it contains from three to four per cent of iron protoxide. The lithiophilite, associated with the green chloritic mineral, has a light clove-brown color. It has a brilliant luster and is clear and transparent. The specific gravity is 3.482. An analysis by Mr. S. L. Penfield afforded the following results:

	I.	II.	Mean.	Atomic relation.	
P ₂ O ₅	45.22	45.22	45.22	P	. . . 0.636
FeO	13.10	12.92	13.01	Fe	0.180 } = 0.631
MnO	31.93	32.12	32.02	Mn	0.451 }
Li ₂ O	9.26	. . .	9.26	Li	0.618 } = 0.628
Na ₂ O	0.28	0.30	0.29	Na	0.010 }
H ₂ O	0.17	. . .	0.17		
Gangue	<u>0.31</u>	<u>0.28</u>	<u>0.29</u>		
			100.26		

The ratio $P : \overset{II}{R} : \overset{I}{R} = 0.636 : 0.631 : 0.628$ corresponds very closely with the formula previously accepted,



It will be observed that the amount of iron in this variety of the mineral is considerably greater than in that first described and alluded to above. This result is not surprising, and indeed was anticipated from the color of the specimen. Mr. Penfield has brought together the analyses of several varieties of triphylite and the two of lithiophilite,* and thus shows the gradations between the two species. The one extreme is the Bodenmais triphylite with 36.21 per cent FeO and 8.96 per cent MnO, and the other the original lithiophilite, with 4.02 per cent FeO, and 40.86 per cent MnO. The relation between these two minerals is closely analogous to that existing between the iron and manganese carbonates, siderite ($FeCO_3$), and rhodochrosite ($MnCO_3$). There is the same similarity in physical characters, the most pronounced difference being here as there in the color, so that the necessity of giving the two minerals of the triphylite group distinct names cannot be questioned.

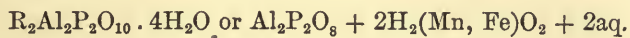
EOSPHORITE.

The eosphorite we have spoken of as forming nodules imbedded in the massive green chloritic mineral. It occurs only massive, but shows the characteristic cleavage distinctly, and is clear and lustrous. The color is a beautiful pink, sometimes quite deep. The specific gravity is 3.11. An analysis by Mr. Horace L. Wells gave the following results:

		Ratio.	
P_2O_5	31.39	0.221	1.06
Al_2O_3	21.34	0.208	1.00
FeO	6.62	0.092	} 2.12
MnO	22.92	0.323	
CaO	1.48	0.026	
H_2O	15.28	0.849	4.04
Insol.	1.46		
	100.49		

* Amer. Jour. Sci., 1879, vol. 17, p. 226.

The ratio of $P_2O_5 : Al_2O_3 : RO : H_2O$ is very nearly 1 : 1 : 2 : 4, or that given in our former paper, and upon which the formula was based, viz. :



The third Branchville paper concludes with descriptions, accompanied by analyses, of a green mineral analogous to chlorite, and of chabazite and rhodochrosite.

DESCRIPTION OF PLATE.

In the figures the letters employed have the following signification: — *a* = albite, though here it is to be remembered that (as remarked earlier) most of the albite contains scales of muscovite, and hence shades into cymatolite; *c* = cymatolite; *g* = muscovite; *k* = killinite; *m* = microcline; *s* = spodumene; β = β spodumene.

1*a*, 1*b*, 1*c*: Three sections across a single crystal, 15 inches wide and 4½ long, at intervals of about 5 inches. 1*a*, from near the terminated extremity, consists principally of β spodumene (β), with cymatolite (*c*) along the edges, and a little glassy spodumene (*s*) on the lower side. 1*b* shows only β spodumene and cymatolite, the latter occupying a larger portion than in 1*a*. 1*c*, from the lower extremity of the crystal shows cymatolite only.

2. Section across a crystal, 4½ inches wide, now entirely altered to cymatolite. The intricate wavy structure of this mineral is shown, as also the tendency of the fibers to be at right angles to the edges.

3. Partial section taken longitudinally; the central portion consists of finely granular albite (*a*), with lines of coarsely granular, and cleavable microcline (*m*); the exterior is cymatolite (*c*).

4. Fragment of a crystal showing the granular albite (*a*) inclosing microcline (*m*).

5. Section across a large crystal; the exterior fractured and irregular. It consists mostly of clear pink spodumene (*s*) with bands of β spodumene (β) passing through it, following the directions of the cleavage; also some cymatolite (*c*) on the exterior.

6. Consists of granular albite (*a*), and cymatolite (*c*), also some plates of mica (*g*).

7. Section across a large crystal (natural size), the interior consisting of fibrous albite (*a*) and the exterior cymatolite (*c*).

8. Section showing some of the original spodumene (*s*) in detached points, with cymatolite (*c*) radiating from them, also some β spodumene, granular albite (*a*), and a few plates of mica (*g*).

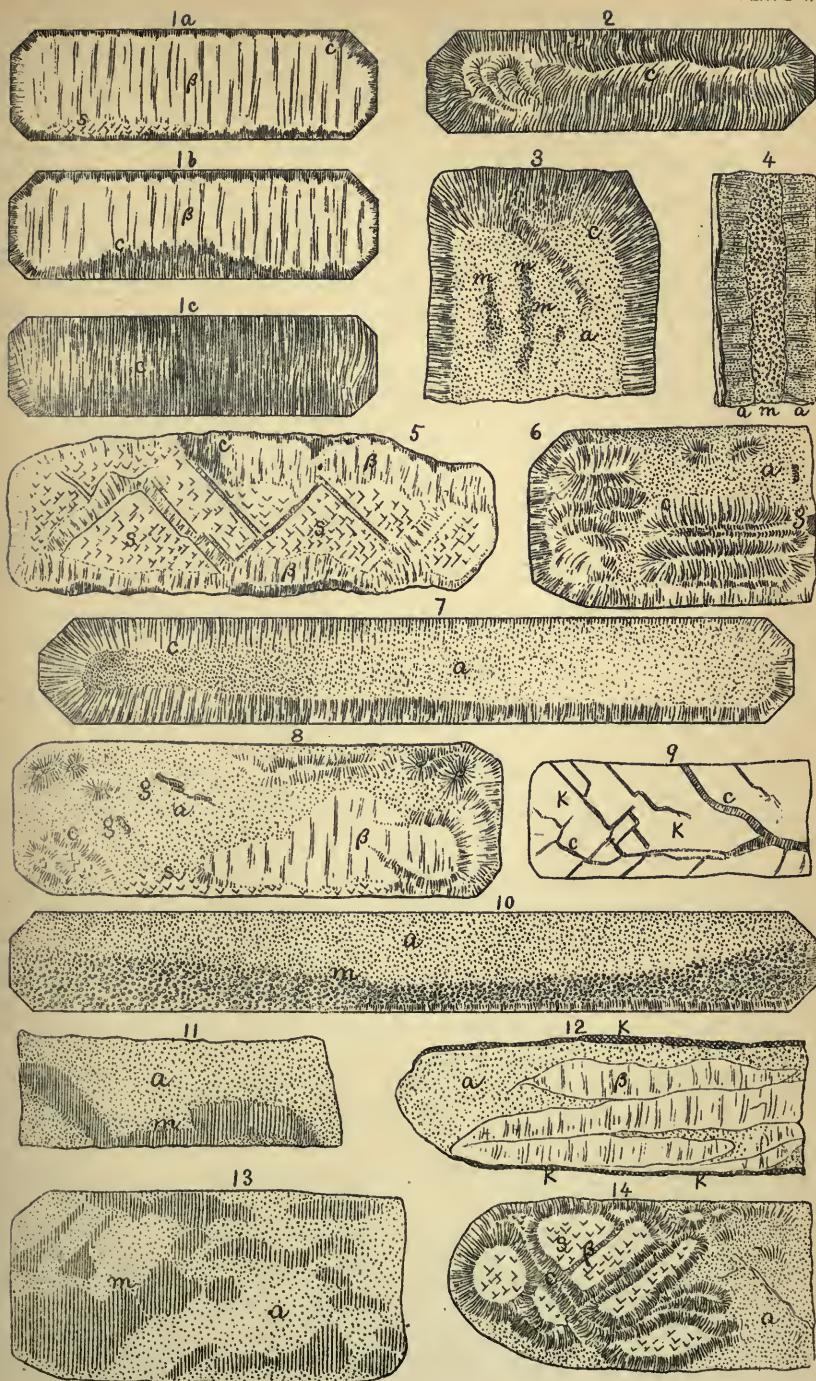
9. A fragment consisting of killinite (*k*) with narrow bands of cymatolite (*c*) following approximately the original cleavage directions of the spodumene.

10. Section across a large crystal (7½ inches wide), consisting of albite (*a*) and granular microcline (*m*).

11, 13. Fragments showing granular albite (*a*) and imbedded in it broad cleavage plates of microcline; in each crystal these plates are all in parallel direction.

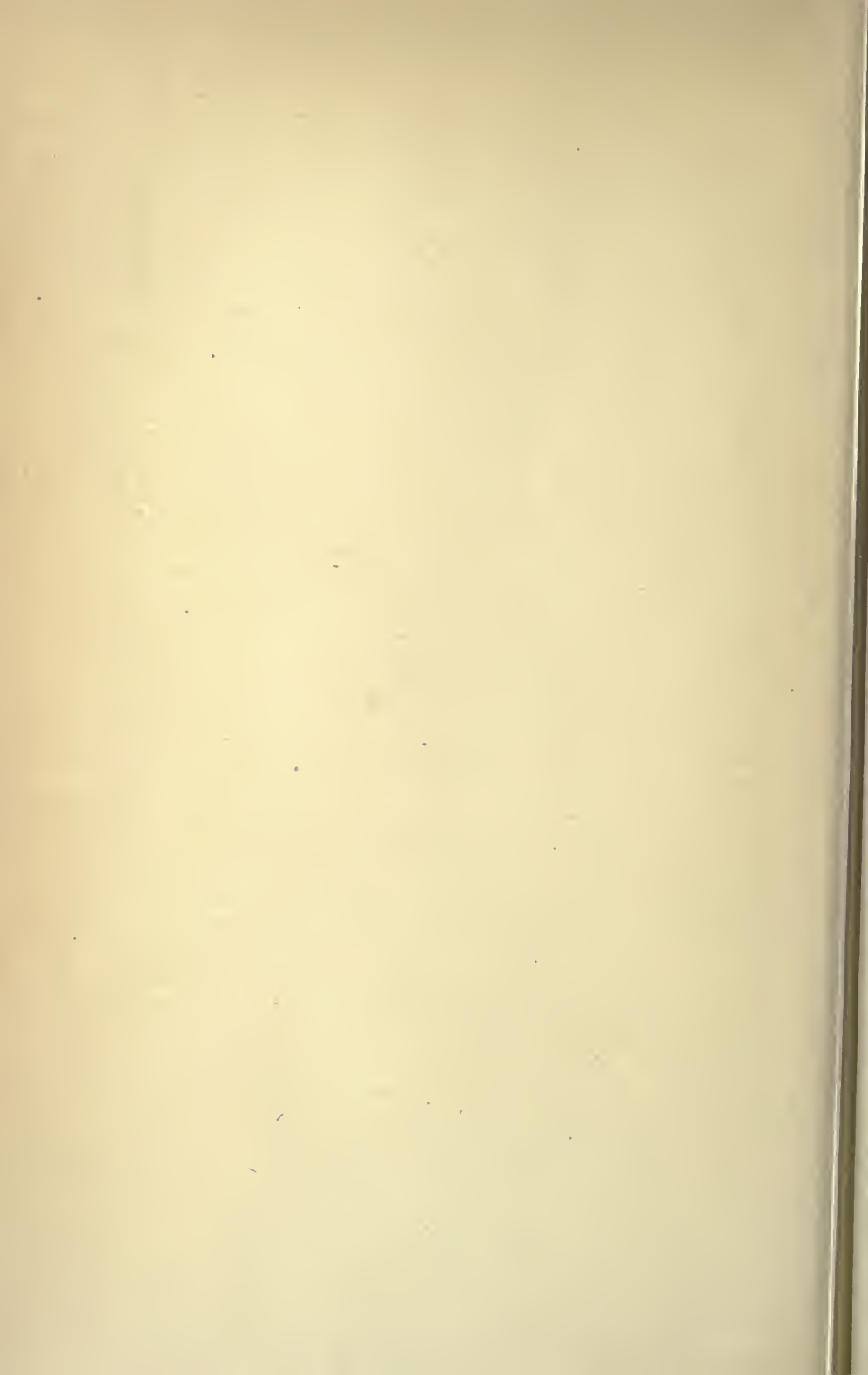
12. Fragment of a crystal, showing β spodumene (β) inclosed in albite (*a*), the exterior portion consisting of killinite.

14. Portion of a crystal with the spodumene (*s*) cymatolite (*c*) radiating from it, and granular albite (*a*); one band through the spodumene is still β spodumene.



J. H. Emerton, del.

Photo Lith. E. Crisand, New Haven, Ct.



panying plate*) is in every case sharply separated from the altered mineral surrounding it, and its characters show that the crystals must originally have had rare beauty. One of the finest crystals that we have found thus far had, as imbedded in the quartz, a length of three feet, a width of eight inches and a thickness of two inches. The unaltered spodumene, of a fine amethystine color, made up about one-fourth of the whole, extending rather regularly through the middle of the crystal. Unfortunately, the spodumene was much rifted and fractured, so that its former transparency had, for the most part, disappeared. The exterior of the crystal consisted principally of β spodumene, with small quantities of cymatolite and albite. Another altered crystal was measured while imbedded in the quartz, of which a length of over *four feet* was exposed. It is not possible to extract these crystals entire, but many fragments have been obtained which have a width of over a foot across the prism and a thickness of two to four inches. In habit the crystals are much like those from Norwich, Massachusetts. They are generally broad or flat, through the development of the orthopinacoid, and comparatively thin; not unfrequently they are well terminated. Occasional stout crystals, having a square prismatic form, much like pyroxene, are also observed.

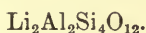
In the better specimens the spodumene is perfectly transparent, sometimes colorless, and again of a beautiful rose-pink or amethystine-purple color. It shows the prismatic cleavage with unusual perfection, and that of the clinopinacoid irregularly. The angle of the prismatic cleavage — viz., $87^{\circ} 13'$ — was obtained with great exactness.

Chemical composition. — An analysis of the transparent pink spodumene was made by Mr. S. L. Penfield with the following results. Specific gravity = 3.193.

* Figures 1 to 14 inclusive are to be found on the accompanying plate, the other figures (15-20) are in the text.

	I.	II.	Mean.		Ratio.	
SiO ₂	64.32	64.18	64.25		1.071	4.00
Al ₂ O ₃	27.14	27.26	27.20	0.262 }	0.263	0.98
Fe ₂ O	0.18	0.22	0.20	0.001 }		
Li ₂ O	7.64	7.59	7.62	0.254 }	0.260	0.97
Na ₂ O	0.39	0.39	0.39	0.006 }		
K ₂ O	tr.	tr.	tr.			
Ignition	0.24	0.24	0.24			
	<u>99.91</u>	<u>99.88</u>	<u>99.90</u>			

The ratio of Li₂O : Al₂O₃ : SiO₂ = 1 : 1 : 4; this corresponds to the oxygen ratio* of 1 : 3 : 8. The formula is then, neglecting the very small amount of soda,



This result agrees exactly with that reached by Døelter in his investigation of the composition of spodumene,† and with that of Julien.‡ It is to be noted, however, that the percentage of lithia here obtained is higher and that of soda lower than in any analyses previously published. For example, Døelter found in the Norwich mineral 7.04 Li₂O, 1.10 Na₂O and 0.12 K₂O; in that from Brazil 7.09 Li₂O and 0.98 Na₂O. Julien obtained in the Goshen spodumene 6.89 Li₂O, 0.99 Na₂O, 1.45 K₂O; and in that from Chesterfield 6.99 Li₂O, 0.50 Na₂O, and 1.33 K₂O. Døelter concludes for the Norwich mineral that the amount of lithia obtained is rather too small than too large, and attributes the soda present to incipient alteration. The correctness of this view seems to be proved by the analyses here published of the Branchville mineral, which certainly left nothing to be desired in regard to purity or freedom from alteration. The great tendency of spodumene to change by the assumption of potash or soda and loss of lithia will be made evident by what follows.

B. ALTERATION OF SPODUMENE.

As the result of the alteration of the spodumene, we have found two substances which at first sight seem to be

* This ratio was obtained by Brush from analyses of the Massachusetts mineral in 1850. See page 30.

† Tschermak, *Min. u. Petr. Mitth.*, i, 517, 1878.

‡ *Annals of the New York Acad. of Sci.*, vol. i, No. 10.

homogeneous, and each of which has a definite chemical composition, and which, notwithstanding, are only intimate mechanical mixtures of two species; one of these, called by us β spodumene, is made up of albite and a new lithia mineral to which we have given the name *eucryptite*; and the other is cymatolite, an aggregate of albite and muscovite. We have also found the following independent minerals:—albite, microcline, muscovite, and killinite. The two complex substances and all of the last named minerals, except the mica, occur as distinct pseudomorphs, having the form of the spodumene. The mica, taken independently of its constant associate the albite, plays only a secondary part. In addition there are other pseudomorphs, of composite character, consisting, as Mr. Julien has well expressed it, “of vein granite.”

We will first give the physical and chemical characters of the various minerals (including the two aggregates) taken separately, and then go on to describe more minutely the way in which they are associated together.

I. PRODUCTS OF THE ALTERATION.

1. β Spodumene.

The substance which we have, for convenience, called β spodumene, since we do not regard it as deserving an independent name, seems to mark the first step in the alteration of the spodumene.

Physical characters.—It is a compact, apparently homogeneous mineral, having a rather indistinct fibrous to columnar structure, this being always at right angles to the adjoining surface of the original mineral. Hardness 5.5 to 6; specific gravity 2.644–2.649. Color white to milk-white, and again slightly greenish-white; translucent. Fusibility = 2.25.

Chemical composition.—Analyses of three independent specimens have been made by Mr. S. L. Penfield. Number 1 was taken from a crystal, part of which consisted of the transparent pink spodumene, described above, and the outer

portion was this mineral (similar to Figure 5). The line of demarcation was perfectly sharp, so that the purity of the material analyzed cannot be questioned. The results of the analysis are as follows:

No. I, G. = 2.649.	I.	II.	Mean.		Ratio.	
SiO ₂	61.35	61.42	61.38		1.023	4.00
Al ₂ O ₃	26.26	25.74	26.00	0.253 }	0.255	0.99
Fe ₂ O ₃	0.24	0.24	0.24	0.002 }		
Li ₂ O	3.63	3.59	3.61	0.120 }	0.254	0.99
Na ₂ O	8.32	8.25	8.29	0.134 }		
K ₂ O	tr.	tr.	tr.			
Ignition	0.46	0.46	0.46			
	100.26	99.70	99.98			

The second portion analyzed was from a fragment of a large and entirely altered crystal; its dimensions were 9 by 8 by $2\frac{1}{2}$ inches. It consisted mostly of cymatolite, and the β spodumene had all the appearance of passing insensibly into it; a single fragment, across the prism, could be obtained made up of both minerals, the fibrous structure of the one being continued in the other (similar to Figure 1b). The analysis yielded:

No. 2, G. = 2.644.	I.	II.	Mean.		Ratio.	
SiO ₂	61.46	61.57	61.51		1.025	4.00
Al ₂ O ₃	[not determined]	26.56	26.56		0.258	1.01
Li ₂ O	3.55	3.44	3.50	0.117 }		
Na ₂ O	8.15	8.13	8.14	0.131 }	0.249	0.97
K ₂ O	0.15	0.15	0.15	0.001 }		
Ignition	0.29	0.29	0.29			
		100.14	100.15			

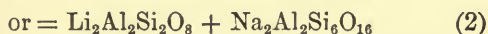
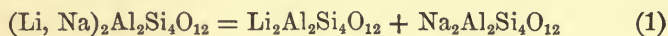
The third portion was part of a smaller and well developed crystal, having the external prismatic form complete. It consisted in the interior of spodumene, then the β spodumene making up the greater part of the whole, and finally a thin crust of cymatolite. The specimen analyzed was, as far as the eye could detect, perfectly pure and homogeneous. The color was greenish-white and it was decidedly translucent. The analysis afforded:

No. 3, G. = 2.649.	I.	II.	Mean.		Ratio.
SiO ₂	61.78	61.64	61.71		1.028 4.00
Al ₂ O ₃	26.57	26.69	26.63		0.259 1.01
Li ₂ O		3.83	3.83	0.128 }	
Na ₂ O		8.16	8.16	0.132 }	0.260 1.01
K ₂ O		tr.	tr.		
Ignition		0.21	0.21		
		<u>100.53</u>	<u>100.54</u>		

If the mean analyses of the three groups be compared, it will be found that they agree very closely with one another; in fact the agreement is as close as could be expected for three successive analyses made upon the same material. But, as will be seen from what has already been said, the three samples were entirely *independent*, being taken from different parts of the ledge and differing in manner of association; the agreement between them thus becomes very striking. The ratio obtained for each,

$$R_2O : R_2O_3 : SiO_2 = 1 : 1 : 4,$$

is the same as that of spodumene, from which it differs only in this: that one-half of the lithium has been removed and its place (chemical equivalent) taken by sodium. The formula is then:



It is shown below that the formula given in (2) is the correct one.

The facts stated thus far would seem to be sufficient to prove that the mineral was homogeneous and had a definite composition; there are, however, other facts which have an important bearing upon this point.

It was found by Mr. Penfield that, although the mineral gelatinizes with acid, it is not entirely decomposed. On the contrary, it is divided into two portions by the treatment with hydrochloric acid, viz.:—a soluble portion (A), and an insoluble remainder (B), the latter including also the silica

extracted from the soluble part. The results of three analyses gave

	A. Soluble in HCl.	B. Insoluble in HCl, with SiO ₂ from A.
No. 1	(17.97)	82.03 = 100.00
" 2	16.65	83.01 = 99.66
" 3	17.91	82.18 = 100.09

In the case of No. 2, complete analyses of both the soluble and insoluble portions were made; these were independent of the total analyses of the same sample already given. The method of analysis was, briefly, as follows:—A gram of the mineral was digested with HCl, evaporated to dryness, then moistened with HCl and a second time evaporated to dryness. After being again moistened with HCl the soluble portion, A above, was filtered off and the alumina and alkalis determined in it by the usual methods. The insoluble portion, which included the silica extracted from A, after being weighed was boiled with Na₂CO₃ and (in the case of No. 3) with a little KOH. By this means the soluble silica of A was dissolved out and the insoluble remainder being weighed, the amount of the soluble silica was determined by the difference. Finally, the insoluble part was analyzed in full by the usual methods. The results of the analyses were as follows:

	No. 2.
B. Insoluble in HCl with silica of A	83.01
Insoluble remainder after treatment with soda	<u>67.56</u>
	15.45
A. Soluble in HCl (16.65), plus silica extracted by soda from B	32.10

The two parts, therefore, into which the original mineral is divided by hydrochloric acid, are:—

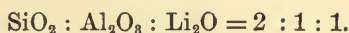
	No. 2.
A. Soluble portion	32.10
B. Insoluble portion	<u>67.56</u>
	99.66

The composition obtained for A was as follows:

A. Soluble portion.

	No. 2.	Calculated to 100. No. 2.	Calculated from formula.
SiO ₂	15.45	48.13	47.51
Al ₂ O ₃	13.00	40.50	40.61
Li ₂ O	3.50	10.90	11.88
K ₂ O	0.15	0.47	. . .
	32.10	100.00	100.00

For the above analysis the ratio is, nearly:



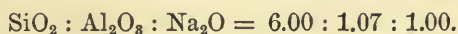
This corresponds to the formula, $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_8$, the percentage composition of which, given above, agrees well with the analysis.

The composition obtained for B was:

B. Insoluble portion.

	No.2.	Calculated to 100. No. 2.	Calculated from formula.
SiO ₂	46.06	68.18	68.62
Al ₂ O ₃	13.56	20.07	19.56
Na ₂ O	7.94	11.75	11.82
	67.56	100.00	100.00

The ratio calculated from the preceding analysis is:



This ratio is very closely that of *albite*, viz.: 6 : 1 : 1, so that the formula for the insoluble portion is $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_{10}$.

An analysis was also made of sample No. 3, but the separation was a little less complete than of No. 2; the first digestion in acid left behind a very little of the soluble mineral, as shown by the presence of lithia in B, and then in the subsequent treatment of the insoluble part (in which also KOH was employed) there seemed to have been a slight decomposition of the albite. The results, although for the reason given hardly worth putting on record, were satisfactory in this, that they confirmed those of No. 2.

The point thus far established may be stated as follows: A chemical examination proves that the substance, called provisionally β spodumene, is not a distinct species, but only a very uniform mixture of two minerals; one of these, called by us *eucryptite*, dissolves with gelatinization in hydrochloric acid, and has the composition, $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_8$; the other, not attacked by acid, is *albite*, $\text{Na}_2\text{Al}_2\text{Si}_6\text{O}_{16}$. The true expression of the chemical composition of the substance, is, therefore, seen to be that (2) given above. That the mixture is truly mechanical, and not a molecular one broken up by the acid (if that were possible), is proved by this significant fact: the insoluble residue (B above), left after the digestion in sodium carbonate, was in one case examined under the microscope, and found to be *crystalline*, and to have the peculiar semi-fibrous structure belonging to the pseudomorphous albite, as described below.

The microscopic examination of thin sections of β spodumene confirms the results reached from the chemical side as to the complex nature of the substance, and gives, in addition, a very satisfactory determination of the crystalline character of the new lithia mineral. A series of thin sections were prepared, some parallel to the fibrous structure, that is at right angles to the original mineral (spodumene), and others transverse to the fibers and consequently parallel to the original prism. The sections parallel to the fibers, when examined under the microscope, seemed at first sight to give no proof of want of homogeneity. The fibers, seemingly of rounded form and generally parallel, are yet quite wavy in outline, and are packed so closely together that the question of the presence or absence of any substance between the fibers and inclosing them could not be answered; the whole gave the effect of aggregate polarization. The above statement is true for the greater portion of each of the slides — the result thus far was negative.

Occasional irregularities, however, in the usually parallel fibrous structure, which may not inaptly be compared in appearance to the grain of wood-fiber in the neighborhood

of a knot, as seen in a smooth board, gave better results. The fibers in such cases are much curved and irregular in outline, and so separated from one another that they are seen to be merely inclosures in a surrounding matrix. In other cases, this inclosing material forms open spots, where the structure (in polarized light) is found to be that of ordinary albite, and into this the needle-like fibers of the other mineral project (this is illustrated in Figure 15, *a* = albite). Still again, on the edges of the sections where a degree of thinness impossible for the whole slide is sometimes attained, a similar satisfactory result is reached. The fibers in such cases are distinctly seen, independently of each other and of the inclosing albite. They are generally nearly straight and parallel, but not infrequently the shape is more or less irregular; branching forms recalling some kind of coralline

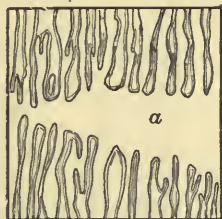


FIGURE 15.

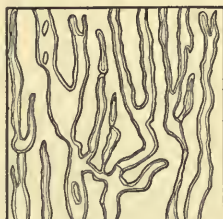


FIGURE 16.

structure are common. The latter forms are shown in Figure 16; the fibers here are much more irregular and coarser than is generally true. (Compare also Figure 19.) The fibers are apparently rounded, but the outlines are usually indistinct, and the form can be made out only by repeatedly changing the focus of the microscope. The explanation of all these irregularities in outline is given by the result obtained on examining the sections cut transverse to the fibers. Several additional facts were brought out in the study of the sections now described. It was found that, when examined between crossed Nicols, the extinction of the light took place *parallel* to the length of the fibers; moreover, the fibers have not infrequently a transverse fracture, probably indi-

cating cleavage. The form of the terminations of the needles could not be certainly observed. In cases like those above described (Figure 15), the extremities seem to be given entire, but no absolute assertion can be made in regard to them. In many cases, probably the majority, they taper out gradually to a fine point, while in others they seem to be terminated by a low pyramid.

The examination of the other set of sections, cut across the fibers, was even more satisfactory and conclusive. The appearance in polarized light, as the plate is revolved on the stage of the microscope, is at once striking and beautiful. The section as a whole is divided into irregular patches (albite), changing from dark to light and the reverse with the revolution, giving the whole a strangely mottled look. Distributed closely and uniformly through this matrix are seen also minute areas of another substance, sometimes curved but generally bent at an angle of 60° or 120° ; they are *unchanged* by the revolution between the crossed Nicols. The effect will be best appreciated from the accompanying

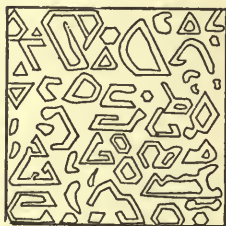


FIGURE 17.

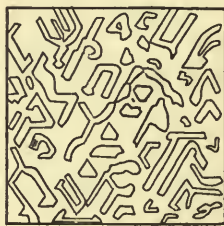


FIGURE 18.

sketches (Figures 17 and 18). When a high power is employed (say 600 diam.) and the attention is confined to a small portion at once, it is seen that these narrow bands, which in a cursory glance under a low power seem to be quite irregular in form, are, on the contrary, approximately in parallel position. The solid portions are triangular or hexagonal in outline, and the bands are bent at angles of 60° and 120° , sometimes so as to form complete rings; — they

are all more or less rounded. In short, the structure is that of the most regular pegmatite or "graphic granite," and the explanation is the same. These regular forms, like those of the quartz in the feldspar in the other case, are due to the restricted crystallization in the albite of the new mineral in question. They mark the mineral as belonging to the hexagonal system, and the result of the optical examination both parallel and transverse to the fibers confirms this conclusion.

Taking the section as a whole, there are portions in which the directions of the new mineral are quite irregular, but for the greater part there is an obvious tendency toward regularity, sometimes leading to most perfect forms. As would be expected, the axial directions (60°) change at small distances, so that a given set of directions belongs only to a limited area; this is obviously determined by the inclosing albite.

We are now able to connect the results of the microscopic examination with those of the earlier chemical investigation. The inclosing material in which the fibers lie is the *albite*; this is proved indeed by what has been stated, and moreover by the fact that it, whenever distinctly separate, has the same structure as in undoubted cases of the same pseudomorphous material; it is also shown by the examination of the insoluble portion alluded to before, for in this the fibers have been removed and the matrix left unattacked. The inclosed mineral is that which with the albite makes up the β spodumene, having the composition $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_8$.

In view of the fact that this lithia-bearing mineral is thoroughly defined, as well crystallographically as chemically, and considering, moreover, the important part it plays in the history of the spodumene, we feel obliged to give it a distinctive name. We call it *eucryptite*, from $\epsilon\upsilon$ well, and $\kappa\rho\upsilon\pi\tau\acute{o}\varsigma$ concealed.

EUCRYPTITE crystallizes in the hexagonal system, with probably basal cleavage. Its specific gravity, calculated from that of β spodumene 2.647, and that of the pseudomorphous albite 2.637, is 2.667. It gelatinizes with hydrochloric acid and fuses easily. It is a unisilicate, and its chemical composition

is expressed by the formula $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_8$ = silica 47.51, alumina 40.61, lithia 11.88 = 100. Its mineralogical relations are not very certain; still, in form, and essentially in composition, it is analogous to nephelite. It also might be viewed as a lithia-anorthite, it having the same ratio as anorthite, though it is different crystallographically. On the other hand, the fact that it changes so readily into muscovite, and has the same ratio as the normal varieties of that species, might seem to place it near it; but it certainly has no micaceous structure. The true lithia mica (lepidolite) has a very different composition.

2. *Cymatolite*.

The name cymatolite was given in 1867 by Professor Shepard to a mineral found at Goshen and Norwich, Mass., a result of the decomposition of spodumene. The analysis given by him left the composition of the supposed new mineral in question, and this doubt was not removed by a subsequent analysis by Mr. B. S. Burton. Mr. Julien gives in his paper several analyses of cymatolite which agree well together and which correspond to a simple chemical formula. In our earlier investigations we assumed it to be an established point that the species was a good one and had a definite composition. This assumption was confirmed by two closely agreeing analyses (given below) made upon the Branchville material. Further study, however, which was made necessary by the results reached in the case of β spodumene — for the cymatolite is directly derived from the β spodumene — has convinced us that the supposed species is only a remarkably uniform and intimate *mechanical mixture of muscovite and albite*. We shall, however, throughout this paper retain the name cymatolite as a convenient way of designating this interesting compound substance, and shall describe it first as if it were a true species.

The *physical* characters of the cymatolite of Branchville are as follows: it has a distinct fibrous structure, sometimes straight but more generally wavy. It is also at times confusedly fibrous and again scaly. The specific gravity = 2.692—

2.699. The color is generally white, but it is often slightly discolored, and occasionally it has a faint pink hue.

As has been stated on a previous page, the crystals of spodumene, which have been altered to cymatolite, are numerous and often very large. The way in which the fibrous structure is developed is seen in Figure 2, which is a section across the prism. It is usually true, as seen here, that the direction of the fibers at the edge is at right angles to the bounding surface. In the interior the structure is more irregular and the fibers interlace in an intricate manner, giving sometimes a feather-like appearance. Usually all trace of the original prismatic structure and cleavage of the spodumene has disappeared. In rare cases, however, in the interior of a crystal this longitudinal structure is still apparent, although the direction of the fibers remains transverse. (Compare also other figures in the plate, in which c = cymatolite.)

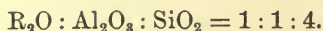
Two analyses of cymatolite have been made by Mr. Penfield. No. 1 was made from a portion of an entirely altered crystal; it was perfectly white and apparently free from any impurities. The results are as follows:

No. 1, G. = 2.692.	I.	II.	III.	Mean.		Ratio.	
SiO ₂	59.38	...	...	59.38		0.989	4.00
Al ₂ O ₃	26.67	...	...	26.67		0.259	1.05
CaO	0.62	...	...	0.62	0.011	0.283	1.13
Na ₂ O	...	7.66	7.70	7.68	0.124		
K ₂ O	...	3.53	3.49	3.51	0.037		
H ₂ O	2.01	...	...	2.01	0.111		
				99.87			

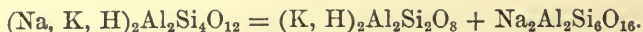
The second analysis was made on the pure mineral associated on the same crystal, which afforded sample 2 of β spodumene. The results afforded are as follows:

No. 2, G. = 2.699.	I.	II.	Mean.		Ratio.	
SiO ₂	60.61	60.49	60.55		1.009	4.00
Al ₂ O ₃	26.37	26.39	26.38		0.256	1.016
MnO	0.08	0.06	0.07			
Na ₂ O	8.08	8.16	8.12	0.131	0.263	1.044
K ₂ O	3.33	3.35	3.34	0.035		
Li ₂ O	0.17	0.17	0.17	0.006		
H ₂ O	1.65	1.66	1.65	0.091		
	100.29	100.28	100.28			

The agreement between these two analyses is as close as could be expected ; the ratio obtained from No. 2 is nearly



This is the same ratio as that obtained for spodumene and β spodumene. The formula is therefore



Since the cymatolite is certainly derived from the β spodumene, while the latter substance has been proved to be a mixture of albite and what — as was shown — has the composition of a lithia muscovite, the fact that the formula of cymatolite can be written as a compound of one molecule *muscovite* and one molecule *albite* is significant. Were no other facts at hand the conclusion that cymatolite also must be a mechanical mixture could hardly be questioned. The facts, however, are in themselves sufficient to prove this, independent of any other considerations. It may be mentioned that the chemical method of attacking the problem, employed in the case of the β spodumene, is not here applicable, since the muscovite is not decomposed by hydrochloric acid. A preliminary examination was made with sulphuric acid, which resulted in showing that the cymatolite was attacked by it, as was the mica of the locality, while the albite was barely so. This method was, however, not carried further, for the microscope gave all the solution that could be desired.

A considerable number of sections of cymatolite, both in its purest normal varieties, and in its transition forms from β spodumene on the one hand and to albite on the other, were examined. The result not only proved the fact of the mixture of muscovite and albite, but also gave the explanation for the remarkable uniformity of the analyses, for in most cases the mixture is in the highest degree intimate. A section of cymatolite like that represented in Figure 1c (Plate), when examined in polarized light, is found to consist of long, slender, somewhat curved fibers, giving very brilliant colors

and showing the characteristic structure of mica, and between them grayish portions of albite. In some cases the fibers of mica are so close together that the albite is invisible, but in others they spread out divergent and then the background of the other mineral is clearly seen. Still again, the mica needles are few, and run out in brilliant lines over a broad surface of albite.

The sections increase in beauty with the irregularity of the structure of the cymatolite. For example, two sections were made from the crystal represented in Figure 2 (Plate). "One of these was, like the figure, transverse, and the other was vertical, and showed something of the prismatic structure of the original spodumene. All the details of the structure came out most clearly in the sections in polarized light. The feather-like structure was particularly distinct and beautiful: a deeply colored rib of mica, and from this diverging regularly on both sides the narrow fibers of the same mineral, the albite between them becoming more and more distinct as their distance apart increased. Other sections were examined of the scaly varieties of cymatolite, where the mica scales were parallel to the surface. In these the albite had the mottled appearance in polarized light, mentioned under β spodumene, and the mica was scattered very uniformly as brilliantly colored scales through it. Other sections transverse to the fibers, in the distinctly fibrous kinds, gave somewhat different effects. Many details could be added, but enough has been said to make the character of the observations apparent on which the statement as to the compound nature of cymatolite is based. The mica and albite are always distinct from one another. In some cases they both appear in larger masses having segregated together in the process of alteration. More is said about this later.

The only foreign mineral observed in the slides was one which occurs in hexagonal prisms, and can hardly be anything but *apatite*, as it agrees optically and crystallographically with that species. It is seen scattered through the cymatolite sometimes rather abundantly, occasionally also in the β spod-

umene, it is, however, not for a moment to be confounded with eucryptite. The presence of apatite would explain the lime found in analysis 1 of cymatolite.

Certain of the sections which show the transition from β spodumene to cymatolite are most interesting and instructive. While in much of the cymatolite there seems to have been a tendency to the partial separation of the mica and albite there are other specimens in which the two are as intimately mixed as the eucryptite and albite in the β spodumene. In cases like those last named, the structure of the cymatolite is exactly that of the β spodumene, only that the rounded fibers of eucryptite have been replaced by the thin elongated scales of mica, proving that the one has been formed from the other. In still other cases we may pass on the same slide from normal cymatolite on the one side to normal β spodumene on the other. Between them is a zone where the two substances shade off into one another, in other words where the change of the eucryptite is only partial. This



FIGURE 19.

will be understood from Figure 19. As here seen, some of the fibers are apparently unchanged, while others are partly altered, the last containing many minute scales of mica, often packed closely together. These small scales are irregularly situated, often across the original fiber of eucryptite: the direction can always be observed both by the cleavage line and too by the direction of the extinction of the light between crossed Nicols. Where the process has been completed, however, the scale of mica is generally parallel to the line of the original eucryptite. The eucryptite fibers along this intermediate zone, even when mica scales are not visible, have generally lost their smoothness of outline, and sometimes have separated into lines of minute, irregular, transparent granules.

The transition of β spodumene into cymatolite can also often be seen by the unaided eye, along the line of contact.

In such cases the silvery lines of mica, though the scales are too minute to be distinguished, can be seen shooting up into the compact β spodumene.

General Summary.—The remarks in the preceding paragraphs may be summed up as follows:—The spodumene was subjected to the action of solutions containing respectively soda and potash. The first action of the soda solution, by the partial exchange of alkali, resulted in the formation, from the spodumene, of an apparently homogeneous but really complex substance, consisting of equal parts molecularly of albite and a new lithia silicate (eucryptite.) A further action of the soda solution (sodium silicate), by the complete change of alkali and the accompanying assumption of silica, led in some cases to the formation of albite. On the other hand, the action of the potash more frequently changed the lithia silicate, above named, into normal muscovite, so that another apparently homogeneous but really complex substance resulted, cymatolite, consisting of muscovite and albite in equal molecular proportions; again, the segregation of these two minerals produced, in place of normal cymatolite, a mixture of separate masses of albite and mica. Still further the action of the potash, by an exchange of alkali and simultaneous assumption of silica, led to the formation of potash-feldspar or microcline. In some cases the result was a coarse mixture of the mica and the two feldspars. Finally, the action of the potash solution, and the simultaneous loss of silica, led to the formation from the original spodumene of a mineral very closely related to mica, namely killinite.

Two questions arise here, to neither of which we can give a very satisfactory answer. The first is as to the source of the soda and potash involved in the changes that have been described—to this nothing more can be said than that they were probably furnished by the previous decomposition of feldspars, though under just what conditions we are unable to say.

The other question is as to the final disposition of the lithia removed from the spodumene—this seems to have disappeared

entirely, unless the fact that some of the biotite in the vein now carries lithia may account for some of it. In this connection it should be stated that the manganese triphylite — lithiophilite — is certainly an original mineral of the vein, and occurs rather abundantly with the massive spodumene. Its decomposition has also led to an increase of this supply of lithia. Furthermore, it is more than possible that the formation of the remarkable series of phosphates of manganese, described by us from this locality, was connected with the extensive changes in the spodumene. The fact that two of the phosphates are almost unique among that group of minerals in containing alkalies (see analyses of dickinsonite and fillowite in our earlier papers) would almost prove this. The lithiophilite may be then the original phosphate of manganese from which the others have been derived. We shall return to this last subject at some future time.

NOTE. — It has been necessary to shorten this article by omitting several pages devoted to descriptions of pseudomorphs of albite, muscovite, microcline, and killinite after spodumene, and a general discussion of pseudomorphs of vein-granite. — EDITOR.

FIFTH BRANCHVILLE PAPER.

BY GEORGE J. BRUSH AND EDWARD S. DANA.

WITH ANALYSES OF SEVERAL MANGANESIAN PHOSPHATES.

BY HORACE L. WELLS.

(From Am. Jour. Sci., 1890, vol. 39, pp. 201-216.)

It is now nearly twelve years since we published our first paper upon the Branchville minerals. It will be remembered that the material which formed the basis of our early work was that which Mr. Fillow had brought to light in his excavations, some two years previous, in search for mica. It was this lot of minerals, sagaciously selected and preserved by Mr. Fillow, that we found so remarkably rich in phosphates of manganese, including a number of new and interesting species. During the years of 1878 and 1879, we carried on a somewhat extended search for these minerals in the ledge from which they had been obtained, but the spot from which the most interesting specimens had been derived was very unfavorably situated for work, being ten feet or more below the level of the ground, and our efforts were only in part successful. Some of the results we have already announced in subsequent papers.

Perhaps the most important result of our early explorations was to prove the presence of large amounts of potash feldspar (microcline) and quartz in the vein — in fact, before we ceased our private work, we had brought to the surface several hundred tons of these minerals. This material was of so excellent quality for technical use and the supply seemed to be so large that negotiations were presently entered into between Mr. Fillow, the owner of the property, and the Messrs. Smith, of the Union Porcelain Works, of Greenpoint, New York,

with the final result of the sale of the property to the latter gentlemen. This was accomplished in 1880. Since that time the work of quarrying for feldspar and quartz has been carried forward uninterruptedly and with gratifying success; up to the present time Mr. Fillow informs us that from three to four thousand tons of feldspar and four thousand tons of quartz have been shipped from the locality. The arrangement has proved also a very successful one from a scientific point of view. The Messrs. Smith have very liberally placed at our disposal all the material obtained from the locality which was of no technical value, while the daily presence of Mr. Fillow, with his active interest and keen eye, has resulted in saving for science practically everything which the locality has yielded. The covering of earth was early removed, and the ledge opened to as great a depth as the drainage would allow; since then the drain has been repeatedly cut deeper until in the summer of 1888, ten years after our first work, the time to which we had been constantly looking forward arrived and the deep spot from which the first supply of phosphates came was reached.

In the mean time, however, the work had not been unproductive, and the contents of our third paper upon certain deposits of lithiophilite, eosphorite and other associated minerals, and of our fourth paper upon the spodumene and its alteration-products, show in part what was accomplished. In addition to what is mentioned in these papers, the locality has at several different times yielded a not inconsiderable amount of uraninite, in part in octahedral crystals with a specific gravity of 9.3; this has been investigated chemically by Comstock.* With the uraninite have been found two or more uranium phosphates which have not as yet been thoroughly studied. Columbite has also been found in considerable quantity, aggregating more than 500 pounds. This occurs in crystalline masses, and in part well developed crystals and groups of crystals in parallel position of remarkable size. It has a specific gravity of 5.73, and as shown by an

* Am. Jour. Sci., 1880, vol. 19, p. 220.

analysis by T. B. Osborne * contains 19.2 per cent of Ta_2O_5 . Another kind of columbite has also been found in minute reddish brown translucent crystals usually implanted upon the spodumene.† This variety Comstock has shown to be exceptionally interesting in the fact that it contains manganese with practically no iron, and further has the niobium and tantalum in the ratio of 1 : 1; it has a specific gravity of 6.59. Other points of interest that have been brought out are the occurrence on a rather abundant scale of a mineral, both massive and indistinctly fully crystallized, which resembles cyrtolite but has not yet been investigated; also of smoky quartz, in part well crystallized, and remarkable for its richness in fluid inclusions (CO_2 , etc.) as described microscopically and chemically by Hawes and Wright; ‡ also of beryl in large columnar masses sometimes two feet or more in length; still further of albite in finely crystallized specimens. Apatite has been found in a variety of forms; one variety, of a dark bluish green, has been found by Penfield § to contain 10.6 per cent of MnO . Other kinds are interesting crystallographically and resemble the Swiss crystals in habit and complexity. Mica has been obtained in limited amount of a merchantable form (300 pounds of plates cut to pattern); the most common variety, however, is that occurring in curved plates, presenting a smooth convex surface like a watch-glass; these aggregates have a radiated as well as concentric structure. Specimens of the Branchville mica have been analyzed by Rammelsberg.||

The most important developments, however, have been those of the summers of 1888 and 1889, when considerable quantities of the manganesian phosphates were brought to light. This result has been especially gratifying to us, since it has given us specimens of all but one of the new species described in 1878, several of which we had almost despaired of finding again. It has also afforded another new member of the triphylite group, a sodium-manganese phosphate, which we shall call *natrophilite*. Besides this we have identified another phosphate

* Am. Jour. Sci., 1885, vol. 30, p. 336.

† Ibid., 1880, vol. 19, p. 131.

‡ Ibid., 1881, vol. 21, pp. 203, 209.

§ Ibid., 1880, vol. 19, p. 367.

|| Jahrb. Min., ii, 224, 1885.

of manganese, and one which from the first we had hoped to find, viz.: the rare mineral *hureaulite*, thus far only certainly known from Limoges, commune of Hureaux, in France.

The general method of occurrence of the phosphates of manganese is such as to confirm the opinion that we have expressed in a former paper, that the manganesian triphylite or lithiophilite is the parent species. This is beyond all doubt an original mineral in the vein, occurring intimately associated with the albite, quartz, and spodumene. With it, sometimes entirely inclosed by it, we find another of the Branchville species, triploidite, which seems to be also an original mineral.

NATROPHILITE.

The sodium-manganese member of the triphylite group, to which we give the name *natrophilite*, has been identified only in the material obtained during the last summer. It occurs sparingly, usually closely associated with lithiophilite, and upon a superficial examination could be confounded with it, although distinguishing characters are not wanting. It appears in cleavable masses for the most part, the cleavage surfaces often broad and showing something of a pearly luster. Occasionally smaller grains appear imbedded in the cleavage mass, and these show at times a more or less distinct crystalline form. On one of these the usual planes of triphylite were identified, 110, 120, 021, 001 (cleavage). The angles could not be obtained accurately but were sufficient to determine the forms, viz.:

	Natrophilite.	Triphylite.
110 $\wedge$ 110 =	50° 30'	47°
120 $\wedge$ 120 =	87°	82° 1'
001 $\wedge$ 032 =	47° — 49°	46° 29'

In crystalline form, then, it agrees, as was to be expected, with triphylite and lithiophilite. Optically it also corresponds so far as it has been investigated; the optic axes lie in the basal section and the acute bisectrix (positive) is normal to the brachypinacoid. The characteristic basal cleavage is always a prominent character, but the brachydiagonal cleavage 010 is

less distinct than is shown by lithiophilite, and the prismatic cleavage (110) is interrupted; the measured angle was 50° ; these cleavages are seen more clearly in thin sections. The fracture is conchoidal, more perfectly so than with lithiophilite. The color is a rather deep wine-yellow, much like that of the Brazilian topaz. The luster is brilliant resinous to nearly adamantine; it was, in fact, the brilliancy of the luster which first attracted our attention, and which is, so far as the eye is concerned, its most distinguishing character. The mineral itself is perfectly clear and transparent, but the masses are much fractured and rifted. The surfaces are often covered by a very thin scale of an undetermined mineral, having a fine fibrous form, a delicate yellowish color, and silky luster. This same mineral penetrates the masses wherever there is a fracture surface of cleavage or otherwise. What the exact nature of this mineral is we are unable to say, since the amount is too small to admit of a satisfactory determination. It appears to be a manganesian phosphate. It is evidently an alteration-product and would seem to imply that natrophilite is rather subject to easy chemical change. In any case, this silky film is one of the characteristic features of the mineral, and directs attention to it at once even over the surface of a hand specimen where it is associated with lithiophilite and perhaps three or four other of these phosphates.

Before the blowpipe natrophilite fuses very easily and colors the flame intensely yellow, thus being at once distinguished from lithiophilite. It also gives the usual reactions for manganese. The following is an analysis of natrophilite made by Wells. The specific gravity on two fragments was found to be 3.40 and 3.42.

	I.	II.	III.	Mean.	Ratio.
P ₂ O ₅	41.03	...	...	41.03	0.289 = 1.00 = 1
MnO	38.19	...	...	38.19	0.538
FeO	3.06	...	...	3.06	0.042
Na ₂ O	...	16.77	16.81	16.79	0.271
Li ₂ O	...	0.20	0.19	0.19	0.006
H ₂ O	...	0.40	0.45	0.43	} 0.277 = 0.97 = 1
Insol.	0.81	0.81	0.81	0.81	
				100.50	

The formula is therefore $\overset{I}{R}_2O \cdot 2\overset{II}{RO} \cdot P_2O_6$ or $\overset{I}{R}\overset{II}{R}PO_4$, or essentially $NaMnPO_4$. It will be noticed that iron is present in very small amount only (3 per cent) and of lithia there is hardly more than a trace (0.2 per cent). With the discovery of natrophilite, the triphylite group receives an important addition, and we now have:

Triphylite, $LiFePO_4$	} Connected by many intermediate compounds, $Li(Fe,Mn)PO_4$.
Lithiophilite, $LiMnPO_4$	
Natrophilite, $NaMnPO_4$.	

These three species are, as is to be expected, closely isomorphous. To them is also related in composition and in some degree in form the new sodium-beryllium phosphate, beryl-lonite, $NaBePO_4$, which was described by one of us a year and a half ago.*

The relation of natrophilite in origin to the common lithiophilite is an interesting question. In view of the extensive changes that, as we have shown, have taken place in the spodumene, by which the lithium has been removed and its place taken more or less fully by sodium, or sodium and potassium, it is natural to suggest that a similar change has resulted in forming the $NaMnPO_4$ out of $LiMnPO_4$, and this we regard as very probable. Its limited method of occurrence suggests the same thing, although it must be remarked at the same time that it seems to pass into hureaulite as readily as the lithiophilite. If in fact formed from lithiophilite, the change probably took place before the formation of most of the other phosphates.

HUREAULITE.

Perhaps the most interesting of recent developments at Branchville is the discovery of the rare mineral hureaulite. Thus far our knowledge of hureaulite has been limited to the account of crystals from Limoges by Dufrénoy† and the later and more thorough description by Damour and DesCloizeaux.‡

* Amer. Jour. Sci., 1888, vol. 36, p. 290; 1889, vol. 37, p. 23.

† Ann. Chim. Phys., xli, 338, 1829.

‡ Ibid, III, liii, 293, 1858.

In addition we have only the single remark by Websky that it probably occurs at Michelsdorf, Silesia, with sarcopside.

The crystals described by DesCloizeaux belong to three varieties showing two distinct types of form, though having the same composition, as shown by Damour. These varieties are respectively violet-rose, brownish orange, and pale rose-pink in color. Their crystallographic relation to each other is anomalous, — in fact, it would be difficult to find another case equally so. The crystals of the two types have the fundamental prism in common, but otherwise no plane of the one occurs on the other, and what is more remarkable, the symbols assigned to a number of the planes of the second type are complex in the extreme. The axial ratio calculated from DesCloizeaux's fundamental measurements is

$$a : b : c = 1.6977 : 1 : 0.8887 ; \beta = 89^{\circ} 27'.$$

The planes observed on crystals of the two types are as follows :

First type.			Second type.		
		DesCl.			DesCl.
<i>b</i>	010	<i>g</i>	<i>a</i>	100	<i>h</i> ¹
<i>c</i>	001	<i>p</i>	<i>m</i>	110	<i>m</i>
<i>m</i>	110	<i>m</i>	<i>o</i>	105	<i>o</i> ⁵
<i>g</i>	301	<i>o</i> ¹ / ₃	<i>a</i>	15 . 0 . 8	<i>a</i> ₁₅ ⁸
<i>e</i>	011	<i>e</i> ¹	<i>δ</i>	435	<i>δ</i>
<i>u</i>	311	<i>u</i>	<i>k</i>	19 . 5 . 8	<i>k</i>
<i>t</i>	341	<i>t</i>	<i>x</i>	11 . 9 . 10	<i>x</i>
			<i>ε</i>	9 . 11 . 10	<i>ε</i>

The Branchville crystals, like those from Limoges, vary in color from pale violet to reddish brown and deep orange-red. The habit of the crystals, however, is nearly constant and the angles also, so far as our measurements have gone; they correspond to the second type of the Limoges crystals. The crystals are not easy to decipher, since they are very small, united by parallel grouping and as a rule present only a few planes in such a way as not to exhibit the symmetry. The angles are not as accurate as could be desired, although the crystals are much better than those of Limoges, since Des-

Cloizeaux gives his observed angles to whole degrees in many cases and the majority are stated to be approximations only.

For the sake of greater simplicity of symbols, the position of DesCloizeaux is modified somewhat in that his plane 105 (o^5) is taken as the base and the pyramid δ is made the unit pyramid.

For fundamental angles the following have been assumed :

$$100 \wedge 001 = 84^\circ 1'$$

$$100 \wedge 110 = 62^\circ 21'$$

$$110 \wedge 401 = 70^\circ 54'$$

whence we obtain :

$$a : b : c = 1.9192 : 1 : 0.5242; \beta = 84^\circ 1'.$$

The observed planes with the symbols of the corresponding planes, so far as observed by DesCloizeaux, are as follows :

		DesCloizeaux.	
a	100	100	h^1
c	001	105	o^5
m	110	110	m
a	401	15.0.8	$a_{15}^{8.5}$
β	501		
p	223		
δ	111	435	δ
e	221	9.11.10	ϵ
k	511	19.5.8	k
z	621		
l	841		

The attempt to transform the symbols of DesCloizeaux, according to the usual methods, into those required by this change of position meets with only partial success. Thus the plane 19.5.8 becomes by the transformation 411 while the observed angles of DesCloizeaux make it for the axial ratio here taken 511. As will be seen below, the angles of a number of forms on the Branchville hureaulite agree pretty well with the angles measured by DesCloizeaux, with the single exception of the prism. For this he found 119° , while we

make it for the Branchville crystals $124^{\circ} 42'$. It is this discrepancy which causes the want of agreement which we have just alluded to. Furthermore, it is seen that the complex symbols of several of the planes, in DesCloizeaux's position and referred to his axes, become simplified when referred to the axes here adopted. Of the planes noted by DesCloizeaux on type 2, all but one ($\bar{1}1.9.10$), it will be seen, occur on the Branchville crystals and to this the symbol $\bar{5}32$ probably belongs in our position. Of the forms of the first type only the prism occurs with us, but to the other planes the probable symbols in our position may be assigned.

DesCloizeaux.		DesCloizeaux.			
001	p	103	$\bar{3}11$	u	$\bar{1}2.3.2?$
011	c^1	153	$\bar{3}41$	t	$\bar{6}61?$

The table of angles, here omitted, gives the more important angles calculated from our axial ratio compared with our measurements and also with the *measured* angles of DesCloizeaux. Although the correspondence between our measured and calculated angles is not in all cases as great as could be desired, the agreement is as close as could perhaps be expected from the nature of the material. It has been stated that the crystals are often grouped in parallel position, but as is common in such cases, the parallelism is not perfect and furthermore the parts show slight variations in position, even when the planes are smooth, which are doubtless to be referred to the same cause.

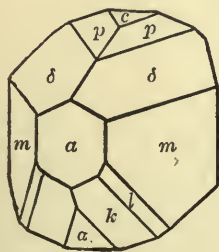


FIGURE 1.

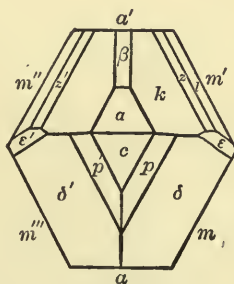


FIGURE 2.

The habit of the Branchville crystals is short prismatic, as shown on Figure 1; a basal projection of a more complex form is given in Figure 2. The grouping in parallel position gives rise to a repetition of the prismatic planes which may result in a deep striation or furrowing of this form. Besides this, the zone of planes *m*, *l*, *k*, *a*, is often striated or channelled parallel to their common direction of intersection. The crystals show rather perfect cleavage parallel to the orthopinacoid. For analysis, carefully selected portions of the purest crystals were taken by Prof. Wells. The specific gravity was found to be 3.149. The results are satisfactory as agreeing fully with those of Damour and leading to the same formula. For comparison we quote Damour's analysis of the pale rose crystals, which differs but little from that of the yellow crystals; it is to be noted that the violet crystals (type I) have not been analyzed and it is possible that some difference in composition may explain the difference noted in the form. The Branchville mineral contains a little less iron than the Limoges.

	I.	Branchville. G. = 3.149. II.	Mean.	Ratio.	Limoges. G. = 3.185.
P ₂ O ₅	38.28	38.44	38.36	0.270 = 1.00 = 2	37.83
FeO	4.76	4.37	4.56	0.063	8.73
MnO	42.29	. . .	42.29	0.596	41.80
CaO	0.94	. . .	0.94	0.17	
H ₂ O	12.25	12.15	12.20	0.678 = 2.51 = 5	11.60
Quartz	1.76	. . .	1.76		Gangue 0.30
			100.11		100.26

The formula is $5\text{RO} \cdot 2\text{P}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$ or $\text{H}_2\text{R}_5(\text{PO}_4)_4 + 4\text{H}_2\text{O}$. The percentage composition calculated for manganese only is: P₂O₅ 38.96, MnO 48.69, H₂O 12.35 = 100.

REDDINGITE.

The species reddingite has been known thus far only in a few specimens, showing it in a granular form of a reddish color, or rarely in octahedral crystals often superficially black from oxidation. The material first found, though scanty, was sufficient to admit of the determination of the form, which was shown to be similar to that of scorodite and strengite.

Among the specimens recently discovered reddingite is not uncommon, and we have been gratified to obtain it not only well crystallized but also in massive form, perfectly fresh and unaltered. The color is a pale rose-pink, often hardly more than a pinkish-white. The most intimately associated minerals are fairfieldite and dickinsonite, the latter of which is often imbedded in it in isolated scales, or more often in stellate groups of green foliæ. The octahedral habit of the crystals, which appear in occasional cavities, is usually apparent at a glance, but not infrequently the crystals are distorted by the elongation of a pair of pyramidal planes, which gives them a misleading oblique prismatic appearance. The common form of the crystals is shown in Figure 6 of our former paper, page 69. Some of the crystals are more complex, Figure 3, and show also the pyramids *r*, *s*, and *t*, whose symbols are respectively 338, 223, 774. These planes do not give sharp measurements, but the angles are sufficient for identification.

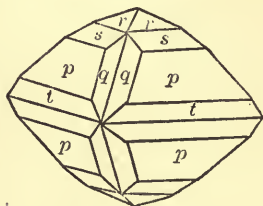


FIGURE 3.

It seemed especially desirable to have a new analysis of this species, both because the material was more abundant and better than what we had had before, and also since the composition — though in fact fully established — may have appeared to some anomalous, in view of its failure to correspond with that of scorodite and strengite in the degree of oxidation of the manganese and in the amount of water. The new analysis by Wells fully confirms the former one made by him, only differing in the larger percentage of ferrous iron present. This analysis of a carefully selected portion with a specific gravity of 3.204 gave:

	I.	II.	Ratio.
P ₂ O ₅	34.90	. . .	0.246 = 1.00 = 1
FeO	17.13	. . .	0.238
MnO	34.51	. . .	0.486
CaO	0.63	. . .	0.011
H ₂ O	13.18	13.18	0.732 = 2.98 = 3
Quartz	0.13		
	100.48		

The formula is hence $R_3(PO_4)_2 + 3H_2O$, and if $R = Fe : Mn = 1 : 2$, this requires P_2O_5 34.64, FeO 17.56, MnO 34.63, H_2O 13.17 = 100.

FAIRFIELDITE.

Fairfieldite appears among the specimens recently obtained not infrequently, and in a form much fresher and purer than that in which we had it before. It is usually in foliated masses intimately associated with reddingite and hardly less so with hureaulite. The color varies from white to yellowish or greenish white; it is usually perfectly transparent and the luster is very brilliant, varying from adamantine to pearly, according to the surface on which it is viewed, the latter on the surface of perfect cleavage. A tendency to crystallization is at times apparent, but no crystals suitable for measurement have been found, which is to be regretted since the early results left much to be desired. An analysis of the perfectly fresh mineral has been made by Wells. This agrees with those of Penfield previously published; the amount of iron is less and that of the manganese greater, but it is worthy of note that the ratio of 2 : 1 for $Ca : Mn + Fe$ is still maintained.* The analysis of pure material having a specific gravity of 3.07 is as follows:

		Ratio.
P_2O_5	[37.69†]	0.265 = 1.00 = 1
FeO	3.42	0.047
MnO	17.40	0.245 } 0.292 = 1.10 = 1
CaO	30.02	0.536 = 2.02 = 2
H_2O	9.81	0.545 = 2.06 = 2
Quartz	1.66	
	100.00	

The formula is hence essentially $Ca_2Mn(PO_4)_2 + 2H_2O$, which requires P_2O_5 39.34, MnO 19.67, CaO 31.02, H_2O 9.97 = 100. This analysis confirms the earlier one by Penfield and further

* It is interesting to call attention here to the identification of fairfieldite by Sandberger at Rabenstein, Jahrb. Min., i, 185, 1885. It is also worthy of note that a new hydrous phosphate of ferrous iron and calcium, near fairfieldite but with $2\frac{1}{2}H_2O$, has been recently named messelite by Muthmann (Zs. Kryst., xvii, 93, 1889); like fairfieldite it is triclinic. Furthermore, the brandtite of Nordenskiöld is $Ca_2Mn(AsO_4)_2 + 2H_2O$, corresponding exactly to fairfieldite, Öfv. Ak. Stockh., 489, 1888, Groth, Tab. Ueb. Min., p. 80, 1889.

† By difference.

makes it probable that there is a definite ratio of 1 : 2 for Mn (with Fe) : Ca.

DICKINSONITE.

One of the most remarkable and novel of the species first described from Branchville was the chlorite-like dickinsonite; a mineral of a bright green color, micaceous structure and pseudo-rhombohedral form. Recent developments have enabled us to add materially to our knowledge of the species. The number of specimens obtained is relatively large, and in some of them it shows itself in tolerably well-defined crystalized forms. It will be remembered that for our earlier work we had only one or two minute crystals. The habit of most of the crystals now found differs from that before described. The hexagonal form is rather rare and the crystals appear as rectangular tables united in slightly diverging groups, Figure 4. A closer examination shows that they agree with the same fundamental form before accepted. These crystals are elongated parallel to the orthodiagonal axis, and the basal surfaces are bent and striated in this direction. In addition they show on the edges, sometimes in traces only, the pyramidal planes, which when developed give the hexagonal habit before noted. In addition to the planes a , b , c , x (301), p ($\bar{1}11$) and s ($\bar{2}21$), we have identified also a steep clinodome, n , which has the symbol (051) and a hemi-orthodome, γ ($\bar{1}03$).

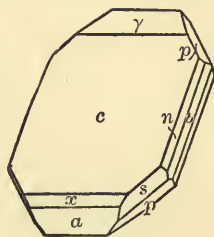


FIGURE 4.

Optically we find the crystals, as before stated, to be biaxial, the optic axes being situated in the clinodiagonal section and the bisectrix nearly normal to the cleavage face; the double refraction is negative and the axial angle large.

Besides the crystals occasionally appearing in the cavities, and often united in slightly diverging groups with edges parallel to b projecting, the mineral occurs foliated to almost massive and granular, the folia, however, usually distinct and often grouped in rosettes or stellate forms.

Dickinsonite is the species about whose composition we felt most doubt when we first published. The material then in hand was very scanty and not entirely pure, and although excellent analyses were made by Penfield, their interpretation was a matter of some doubt because of admixture of more or less eosphorite as well as quartz. Two independent sets of new analyses have been made by Professor Wells. The material for the first was picked with great care, but in order to remove all question as to whether the results gave the true composition of the mineral, a second and independent analysis was made. For this the very best material was selected and after being separated was minutely examined microscopically to make sure of its purity. The results, as will be seen, are identical with those of the first.

DICKINSONITE, BRANCHVILLE.

Analysis of first sample.

	Sp. gr. 3.143.			Ratio.
	I.	II.	Mean.	
P ₂ O ₅	39.57	. . .	39.57	0.279 = 1.00 = 1
FeO	. . .	13.25	13.25	0.184
MnO	31.74	231.4	31.58	0.445
CaO	2.15	. . .	2.15	0.089
MgO	trace			0.814 = 2.92 = 3
Na ₂ O	7.47	7.44	7.46	
K ₂ O	1.49	1.55	1.52	
Li ₂ O	0.20	0.14	0.17	
H ₂ O	1.66	1.65	1.65	0.094 = 0.34 = $\frac{1}{3}$
Quartz	2.58	2.58	2.58	
			99.93	

Analysis of second sample.

	I.	II.	Mean.	Ratio.
P ₂ O ₅	40.89	. . .	40.89	0.288 = 1.00 = 1
FeO	12.96	. . .	12.96	0.180
MnO	31.83	. . .	31.83	0.448
CaO	2.09	. . .	2.09	0.088
MgO	none	. . .		0.811 = 2.82 = 3
Na ₂ O	. . .	7.37	7.37	
K ₂ O	. . .	1.80	1.80	
Li ₂ O	. . .	0.22	0.22	
H ₂ O	1.64	1.62	1.63	0.092 = 0.32 = $\frac{1}{3}$
Quartz	0.85	0.79	0.82	
			99.61	

The two samples were picked from separate specimens and the material was apparently very pure. Unusual care was taken in picking the second sample, and its purity is indicated by the small amount of quartz present.

The formula indicated by both the analyses is $3\text{RO} \cdot \text{P}_2\text{O}_5$, $\frac{1}{3}\text{H}_2\text{O}$ or $\text{R}_3(\text{PO}_4)_2 + \frac{1}{3}\text{H}_2\text{O}$ where $\text{R} = \text{Mn, Fe, Ca, Na}_2, \text{K}_2$ and Li_2 . There is no simple ratio between the alkalies and the remaining bases. The results vary considerably from those of Penfield in his original analysis. This is undoubtedly due to the fact that the present material was much purer than that analyzed by him. Penfield found about 14 per cent CaO , (probably due to admixed fairfieldite) only about 6 per cent of alkalies and 3.87 per cent of H_2O . The formula which he arrived at, however, is confirmed except in the amount of H_2O . It will be seen that the composition now established is essentially the same with that deduced for fillowite on the basis of Penfield's original analysis.

FILLOWITE.

The fact just stated, that our former formula for fillowite is the same as that now obtained for dickinsonite, has made us very anxious to prove that our early results were trustworthy, especially since the material in hand at the time of our first investigation was very scanty. Unfortunately, among the large number of specimens recently obtained from Branchville, we have not succeeded in finding a trace of this mineral. We have been forced consequently to revert to the few original specimens still in hand. The best of these we gave to Mr. Wells, and from it he picked out about 0.75 gram, in the homogeneity of which he had entire confidence. A new analysis of this has been made by him with the following results; for comparison we quote the original analysis by Penfield.

			Ratio.		Analysis (1878) Penfield.
P ₂ O ₅	39.68		0.279	1.00	39.10
Feo	9.69	0.135	0.847	3.04	9.33
MnO	39.58	0.557			39.42
CaO	3.63	0.065			4.08
Na ₂ O	5.44	0.088			5.74
Li ₂ O	0.07	0.002			0.06
H ₂ O	1.58		0.088	0.31	1.66
Quartz	1.02				0.88
	<u>100.69</u>				<u>100.27</u>

It will be seen that the two analyses agree throughout and the formula is the same, viz.: $R_3P_2O_8 + \frac{1}{3}H_2O$. As noted above, it is identical with that of dickinsonite, although the latter species contains more alkalis and less manganese. The two species are then essentially dimorphous forms of the same compound, and the relation between them is made all the more interesting in that with the striking differences in physical characters, there is yet an obvious relation in form. Dickinsonite is monoclinic with marked pseudo-rhombohedral symmetry and of fillowite the same is true as we have proved by a reëxamination of fragments parallel to the distinct but interrupted basal cleavage. Moreover, the dimensions of the forms show a close relation, thus we have:

	Dickinsonite.	Fillowite.
100 $\wedge$ 001 =	61° 30'	58° 31'
001 $\wedge$ $\bar{2}$ 21 =	61 8	58 40

We have then in these two species an example of a very close and interesting case of dimorphism. The suggestion that the two could be regarded as independent forms of the same mineral differing in habit and state of aggregation could not possibly be made by one who had seen and examined the specimens. We have still hope that in future explorations at Branchville we may find a new supply of this rare and interesting species, named in honor of our good friend, Mr. A. N. Fillow.

CONCLUSION OF THE BRANCHVILLE PAPERS.

ON THE CHEMICAL COMPOSITION OF AMBLYGONITE.

By SAMUEL L. PENFIELD.

(From Amer. Jour. Sci., 1879, vol. 18, pp. 295-301.)

THE new mineral species triploidite described by Messrs. Brush and Dana * is shown by them to be isomorphous with wagnerite and closely related in composition to triplite. These three minerals have respectively the formulas $(\text{Mn,Fe})_3\text{P}_2\text{O}_8 + (\text{Mn,Fe}) (\text{OH})_2$, $\text{Mg}_3\text{P}_2\text{O}_8 + \text{MgF}_2$ and $(\text{Fe,Mn})_3\text{P}_2\text{O}_8 + (\text{Fe,Mn})\text{F}_2$. From a comparison of these formulas it is argued, page 60, that the relation between the minerals requires the assumption that the hydroxyl in triploidite must play the same part as fluorine in the other two.

In this paper it will be shown that in amblygonite the hydroxyl group is also isomorphous with fluorine, and that in chemical composition the original amblygonite does not differ from the American and Montebbras varieties which have been called hebronite. It will also be shown that the results of the analyses require the adoption of a new formula for the mineral, more simple than that previously accepted. For analysis specimens have been selected from three localities in Maine, from Branchville, Connecticut, where the mineral has been lately discovered by Messrs. Brush and Dana, also two varieties from Montebbras and one from Penig, Saxony, the last from a specimen in the Yale College collection.

The analyses are arranged so as to form a series, beginning with the one which contains the smallest amount of water. The results of the analyses may be tabulated as follows: †

* Page 57.

† The analyses were made in duplicate, and in the original article the results of all the determinations are given. The figures here given are the averages of duplicate determinations as they appeared in the original article. In No. IV. the P_2O_5 determination was lost, and the result given is that obtained by difference.—EDITOR.

- I. From Penig, Saxony.
- II. From Montebas, France, variety A, sp. gr. 3.088.
- III. From Auburn, Maine, sp. gr. 3.059.
- IV. From Hebron, Maine, variety A.
- V. From Paris, Maine, sp. gr. 3.035.
- VI. From Hebron, Maine, variety B, sp. gr. 3.032.
- VII. From Branchville, Connecticut, sp. gr. 3.032.
- VIII. From Montebas, France, variety B, sp. gr. 3.007.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
P ₂ O ₅	48.24	47.09	48.48	[48.53]	48.31	47.44	48.80	48.34
Al ₂ O ₃	33.55	33.22	33.78	34.12	33.68	33.90	34.26	35.55
Li ₂ O	8.97	7.92	9.46	9.54	9.82	9.24	9.80	9.52
Na ₂ O	2.04	3.48	0.99	0.84	0.34	0.66	0.19	0.33
K ₂ O	...	...	...	...	0.03	...	...	...
H ₂ O	1.75	2.27	3.57	4.44	4.89	5.05	5.91	6.61
F	11.26	9.93	6.20	5.24	4.82	5.45	1.75	1.75
CaO	...	0.24	...	...	...	...	...	0.35
F ₂ O ₃	...	...	...	...	...	...	0.29	...
Mn ₂ O ₃	0.13	...	...	...	...	...	0.10	...
	<u>105.94</u>	<u>104.15</u>	<u>102.48</u>	<u>102.21</u>	<u>101.89</u>	<u>101.74</u>	<u>101.10</u>	<u>100.45</u>
O = F	<u>4.74</u>	<u>4.02</u>	<u>2.61</u>	<u>2.21</u>	<u>2.03</u>	<u>2.29</u>	<u>0.74</u>	<u>0.74</u>
	101.20	100.13	99.87	100.00	99.86	99.45	100.36	99.71

For more easy comparison the ratios from the foregoing analyses are collected in the following table by themselves, where $\bar{R}$ equals Li and Na.

	P	Al	$\bar{R}$	(OH, F)
I.	1.00	0.96	0.98	1.16
II.	1.00	0.97	0.98	1.17
III.	1.00	0.96	0.97	1.06
IV.	1.00	0.97	0.95	1.13
V.	1.00	0.96	0.97	1.17
VI.	1.00	0.98	0.95	1.27
VII.	1.00	0.97	0.96	1.09
VIII.	1.00	0.96	0.96	1.21

It will be seen that all of these approach closely to the ratio 1 : 1 : 1 : 1, hence $\text{Al}_2\text{P}_2\text{O}_3 + 2\text{R}(\text{OH}, \text{F})$ is proposed as the true formula for all varieties of this mineral.*

* A better way to express the composition of the mineral is to regard it as containing the isomorphous fluorine and hydroxyl molecules, $\text{Li}[\text{AlF}]\text{PO}_4$ and $\text{Li}[\text{AlOH}]\text{PO}_4$, which may be written $\text{Li}[\text{Al}(\text{F}, \text{OH})]\text{PO}_4$.—EDITOR.

DesCloizeaux, from a difference in optical characters made out by him, has divided the mineral into two species: the original amblygonite, including I and II in the foregoing list; and a second species for which he proposed the name *montebrasite* (hebronite of von Kobell), including analyses III to VIII above. The mineral from Branchville has not been examined optically and the material is very unfavorable for such an examination. Owing to the close identity in chemical composition it seems that a slight variation in optical properties is hardly sufficient ground for dividing the mineral into two species, but on the contrary it is believed that the old name amblygonite should be retained, and that all varieties should be included by it. A description of the method of analysis is here omitted.

ON THE CHEMICAL COMPOSITION OF CHILDRENITE.

By S. L. PENFIELD.

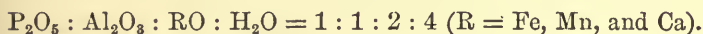
(From Amer. Jour. Sci., 1880, vol. 19, pp. 315-316.)

AFTER the publication by Messrs. Brush and Dana* of their paper in which the new species, eosphorite, was described and shown to be closely related both physically and chemically to childrenite, they proposed to me to make a new investigation of the composition of the latter species with a view to deciding the uncertainty in regard to its true formula. Professor Brush very kindly provided and placed at my disposal a specimen out of his collection from Tavistock. From this the material for the following analysis was taken. The crystals were small, of a yellow-brown color, and were very carefully picked from the siderite and oxide of iron with which they were associated. Only lustrous crystals were accepted, and any doubtful material was discarded. Between eight and nine tenths of a gram were thus obtained. Analysis I is a complete analysis made on a little over half a gram; it was conducted with the greatest care and a special test was made for alkalies, so that they might be determined quantitatively if present. As Church in his analysis found iron sesquioxide present, the remaining three tenths of a gram of the mineral were tested quantitatively with potassium permanganate; the result indicated 26.08 per cent of FeO, varying only 0.12 per cent from gravimetric determination of iron protoxide in the same portions; so that we may conclude that the mineral really contained no iron sesquioxide. After titrating with potassium permanganate the solution was reserved, and P_2O_5 ,

Al_2O_3 and FeO determined in it gravimetrically (analysis II) as a control on the other analysis.

	I.	II.		Ratio calculated from analysis I.
P_2O_5	30.19	29.98	0.212	1.00
Al_2O_3	21.17	21.44	0.208	0.98
FeO	26.54	26.20	0.368	} 0.458 2.16
MnO	4.87		0.069	
CaO	1.21		0.021	
H_2O	15.87		0.882	4.16
Quartz	0.10			
	99.95			

The above ratio corresponds closely to the following:



This gives the empirical formula $\text{R}_2\text{Al}_2\text{P}_2\text{O}_{10} \cdot 4\text{H}_2\text{O}$, which may be written, $\text{Al}_2\text{P}_2\text{O}_8 + 2\text{R}(\text{OH})_2 + 2\text{aq.}$, the same as that made out for eosphorite.

The formula in this case corresponds to the following percentage composition: P_2O_5 30.80, Al_2O_3 22.81, FeO 26.37, MnO 4.87, H_2O 15.65 = 100. This agreed satisfactorily with analysis I.

NOTE. — The water in eosphorite is wholly driven out at a very low temperature; hence it may be concluded that eosphorite and childrenite contain water of crystallization and *not hydroxyl*. The general formula of these minerals should therefore be written as follows: $\text{R}[\text{AlO}]\text{PO}_4 \cdot 2\text{H}_2\text{O}$. In eosphorite $\text{R} = \text{Mn}$ and a little Fe , in childrenite $\text{R} = \text{Fe}$ and a little Mn . Both contain the univalent radical $[\text{AlO}]$. — EDITOR.

BASTNÄSITE AND TYSONITE FROM COLORADO.

BY O. D. ALLEN AND W. J. COMSTOCK.

(From Amer. Jour. Sci., 1880, vol. 19, pp. 390-393.)

THE material for the investigation the results of which are here given, was received from Messrs. S. T. Tyson and H. E. Wood, to whom our thanks are due.

The first mineral examined was found by careful qualitative analysis to contain only the metals of the cerium group, fluorine, and carbonic acid, with a trace of iron. Its characters are as follows: Hardness = 4-4.5. Sp. gr. = 5.18, 5.20. Luster vitreous to resinous. Color reddish brown. Streak light yellowish gray. Infusible. It is very slightly attacked by hydrochloric acid, without perceptible evolution of carbonic acid. Strong sulphuric acid dissolves it with evolution of carbonic and hydrofluoric acids. Strongly heated in a closed tube shows scarcely a trace of moisture. The direct results obtained by analysis are:

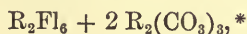
	I.	II.	Mean.	Swedish bastnäsite by Nordenskiöld.	
Ce ₂ O ₃	40.88	41.21	41.04	} 75.80	28.49
(La, Di) ₂ O ₃	34.95	34.56	34.76		45.77
CO ₂	20.09	20.20	20.15		19.50

By converting a known weight of the mixed oxides of the mineral into anhydrous normal sulphates, the joint atomic weight of the metals was found to be 140.2. If from the carbonic acid obtained, an amount of the bases is calculated sufficient to form normal carbonate, the remainder of the bases calculated as metals and the fluorine estimated by difference, the mean becomes:

		Ratio.
(Ce, La, Di) ₂ O ₃	50.13	0.153
Ce, La, Di	21.82	0.155
CO ₂	20.15	0.458
Fl	7.90	0.416
	<u>100.00</u>	

$$\text{R}_2\text{O}_3 : \text{R} : \text{CO}_2 : \text{Fl} = 1 : 1.01 : 3 : 2.72,$$

corresponding to the formula



in which R = Ce, La, and Di. If the atomic weight of R = 140.2, as found in the present case, the formula requires :

(Ce, La, Di) ₂ O ₃	49.94
Ce, La, Di	21.32
CO ₂	20.07
Fl	8.67
	<u>100.00</u>

This mineral corresponds to that from Sweden described by Hisinger † under the name of Basiskfluorcerium. It was later reinvestigated by A. E. Nordenskiöld, ‡ who first ascertained its correct composition and called it *hamartite*. Huot had, however, previously called the mineral *bastnäs*ite, after the locality. Nordenskiöld's analysis is given above for comparison.

Associated with *bastnäs*ite occurs a mineral which proved to be an anhydrous normal fluoride of cerium, lanthanum, and didymium, which we have examined with the following results :

$$\text{H} = 4.5-5.$$

$$\text{Specific gravity} = 6.14, 6.12.$$

Luster vitreous to resinous. Color pale wax-yellow. Streak nearly white. B. B. blackens but does not fuse. In closed tube decrepitates, the color changes to a light pink, and shows slight traces of moisture. Insoluble in hydrochloric and nitric acids, but dissolves in concentrated sulphuric acid

* The formula may best be written, $[\text{RF}]\text{CO}_3$, R = Ce, La and Di. — EDITOR.

† Cef. Ak. Stockh., 1838, p. 187.

‡ Cef. Ak. Stockh., 1868, p. 399.

with evolution of hydrofluoric acid. Qualitative examination showed only the presence of fluorine and the metals of the cerium group.

Quantitative analysis gave the following results:

	I.	II.	Mean.	Ratio.	
Ce	40.16	40.22	$40.19 \div 141.2 = 0.284$	} 0.504	
La, Di	30.29	30.45	$30.37 \div 138 = 0.220$		
Fl (diff.)	29.55	29.33	29.44		1.547
	100.00	100.00	100.00		

From which is obtained the ratio

$$R : Fl = 1 : 3.07.$$

The formula (Ce, La, Di) Fl_3 appears therefore to express the composition of the mineral. As this mineral differs essentially in chemical composition and physical properties from any mineral hitherto described, it should be regarded as a new species. We propose for it the name *tysonite*.

The process of analysis used for both minerals was as follows: a solution was effected by strong sulphuric acid. After removing the excess of sulphuric acid the sulphates were dissolved in water. The bases were precipitated with ammonium oxalate, the oxalates ignited in air and finally in hydrogen in order to remove the slight amount of oxygen which Di_2O_3 takes upon ignition in air. The cerium in the mixed oxides was determined volumetrically by Bunsen's method. The CO_2 was determined by ignition in a combustion tube with lead chromate mixed with a little fused potassium dichromate. A trial of this method with pure calcium carbonate mixed with calcium fluoride gave satisfactory results.

Locality and mode of occurrence. — The material first furnished to us by Messrs. Wood and Tyson came from a locality at that time unknown to them, and consisted of a few grams of fragments of crystals of bastnäsite, to some of which were attached portions of the tysonite, readily distinguishable by its lighter color and perceptible cleavage, which is wholly

lacking in the bastnäsite. Mr. Tyson, having recently succeeded in reaching the locality, which is near Pike's Peak, has just placed in our hands for examination all the specimens which he could obtain, about a dozen crystals and fragments of crystals, the largest of which are upwards of an inch in diameter, mostly free, but in some cases attached to feldspar.

The crystals are hexagonal in form, the only planes observed being c (0001), m ($10\bar{1}0$) and a ($11\bar{2}0$). On a single crystal can be seen the remains of pyramidal planes, but so rounded by abrasion that any measurements would be useless. The crystals are prismatic in habit, the smaller ones slender and somewhat elongated, the larger ones short and thick.

These specimens show an interesting relation between the fluoride and the fluo-carbonate. The smaller crystals consist wholly of fluo-carbonate; in the larger crystals, however, a portion occupying the interior, about equally distant from the basal planes, usually about half an inch from them and extending nearly to the lateral planes, consists of the *fluoride*. The thickness of this band varies with the length of the crystals from a few lines to half an inch. The line of demarkation between it and the fluo-carbonate is quite distinct. This mode of occurrence of the two compounds, being such as is often seen in crystals which have undoubtedly undergone partial changes of composition, leads to the conclusion that the bastnäsite of Colorado was formed by a change of a fluoride into a fluo-carbonate. In the fluoride a distinct but not strongly marked cleavage exists parallel to the basal planes of the inclosing fluo-carbonate. In the latter we could detect no evidence of cleavage.

CRYSTALLIZED TIEMANNITE AND METACINNABARITE.

By SAMUEL L. PENFIELD.

(From Amer. Jour. Sci., 1885, vol. 29, pp. 449-454.)

1. TIEMANNITE.

IN October last, Professor J. E. Clayton, president of the Salt Lake Mining Institute, sent to Professor Brush a few specimens containing crystals of a selenide of mercury which were suitable both for analysis and measurement. The specimens were from Marysvale, Southern Utah, the same locality which afforded the sulpho-selenide of mercury, onofrite,* described by Professor Brush. A description of the occurrence of the mineral, as stated by Prof. Clayton, is given at the end of this article, and I take great pleasure in here expressing to him my thanks for calling our attention to these most interesting crystals.

The crystals are black, with high metallic luster and black streak; hardness about 3; specific gravity taken twice on a chemical balance 8.188-8.187; fracture conchoidal; very brittle and with no apparent cleavage.

An analysis was made by decomposing the mineral in a current of chlorine gas, precipitating the mercury as subchloride by means of phosphorous acid and the selenium with sulphurous anhydride. The results are given below with the determinations of small amounts of sulphur, cadmium and insoluble residue.

* Amer. Jour. Sci., 1881, vol. 21, p. 312.

		Ratio.		
Se	29.19	0.369	} 0.381	1.00
S	0.37	0.012		
Hg	69.84	0.349	} 0.352	0.92
Cd	0.34	0.003		
Insol.	0.06			
	99.80			

The ratio of the selenium plus sulphur to the metals is 1 : 0.93 or nearly 1 : 1, as required by a normal selenide, and as the impurities are present only in very small quantities the mineral may be regarded as a simple selenide of mercury. The analysis agrees more closely with the theoretical requirements than any previously published, which may be in consequence of the greater purity of the crystallized material.

The crystals measure up to 3 mm. in diameter. They are isometric, tetrahedral, and the habit of the few at my disposal is quite various. The plus and minus tetrahedrons are usually about equally developed and vary in luster; the cubic faces are also prominent and are at times striated diagonally parallel to their intersection with the dullest tetrahedron and

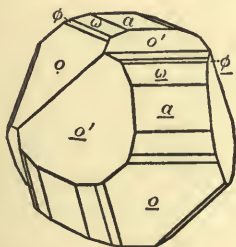


FIGURE 1.

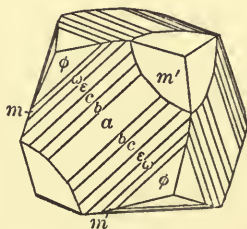


FIGURE 2.

most developed tristetrahedron forms. Twins with *o* as the twinning-plane are common. Taking the forms of the most developed tristetrahedron as positive, the observed forms are as follows: *o*(111), usually dull, *o'*(111) lustrous, *a*(100), *w*(511) and ϕ (733). The above forms were all observed on one twin crystal, Figure 1, the latter ϕ , as a very small face but giving distinct reflections. The faces in both halves of

the twin crystal figured are lettered alike except that those in twin position are underscored. Twins on the specimens in my possession are more common than single crystals, some of them showing simply both tetrahedrons and cube.

The measured angles are the following, the mean of closely agreeing results being given:

	Observed.	Calculated.
$o \wedge o', 111 \wedge \bar{1}11 = 70^\circ 31'$		$70^\circ 32'$
$a \wedge o', 001 \wedge \bar{1}11 = 54^\circ 45'$		$54^\circ 44'$
$a \wedge \omega, 001 \wedge 115 = \begin{matrix} 15^\circ 45' \\ 15^\circ 50' \end{matrix} \}$		$15^\circ 48'$
$a \wedge \phi, 001 \wedge 337 = 31^\circ 10'$		$31^\circ 13'$

A number of crystals have the habit shown in Figure 2; only one was lustrous enough to admit of measurement. The zone a, b, c , etc., was very much striated and distorted through oscillatory combination, but by turning the crystal so as to catch the light reflected from it, it could be readily seen to consist of several distinct forms. On the reflecting goniometer the signal was reflected from the faces in almost an unbroken band; a few of the most prominent reflections, however, were recorded and are given below. The reflection from the faces of a lamplight placed at a distance across a large room was resorted to, all the faces of like inclination reflecting together and yielding a sort of "schimmer Messung;" the results of which, although not very exact, being sufficiently so to fix the symbols of the different forms. The measurements taken on both sides of, and measured from, the cubic face a , are given below.

	b	c	ϵ	ω	m	ϕ	
Direct reflection	$6^\circ 11'$	$9^\circ 17'$	$12^\circ 30'$				} right.
Schimmer	$\begin{matrix} 6^\circ 17' \\ 6^\circ 25' \end{matrix}$	$\begin{matrix} 9^\circ 24' \\ 9^\circ 49' \end{matrix}$	$\begin{matrix} 12^\circ 42' \\ 12^\circ 58' \end{matrix}$	$\begin{matrix} 17^\circ 17' \\ 17^\circ 16' \end{matrix}$			
Direct reflection	$6^\circ 12'$						} left.
Schimmer	$\begin{matrix} 6^\circ 7' \\ 5^\circ 50' \end{matrix}$	$\begin{matrix} 9^\circ 17' \\ 9^\circ 2' \end{matrix}$	$\begin{matrix} 12^\circ 20' \\ 11^\circ 47' \end{matrix}$	$\begin{matrix} 16^\circ 26' \\ 16^\circ 20' \end{matrix}$	$\begin{matrix} 25^\circ 7' \\ 25^\circ \end{matrix}$	$31^\circ 23'$	
Mean	$6^\circ 10'$	$9^\circ 22'$	$12^\circ 27'$	$16^\circ 47'$	$25^\circ 3'$	$31^\circ 23'$	

Calculated for the following forms:

$$001 \wedge 1.1.13 = 6^{\circ} 13'$$

$$001 \wedge 2.2.17 = 9^{\circ} 27'$$

$$001 \wedge 2.2.13 = 12^{\circ} 6'$$

$$001 \wedge 115 = 15^{\circ} 48'$$

$$001 \wedge 113 = 25^{\circ} 14'$$

$$001 \wedge 337 = 31^{\circ} 13'$$

The reflections from ω , m and ϕ were very faint, that from ϕ being the last trace of reflected light which could be seen on turning the crystal. The measurements agree quite well among themselves, considering the method used, and warrant my taking the above symbols according to which Figure 2 is drawn. The form $\omega(511)$ shows the greatest variation, but, as it is a prominent form on the simpler and more perfect crystals, it seems better to regard the variation as due to error in measurement than to take the less probable symbol (922) with calculated value $17^{\circ} 27'$. The only other form $m'(3\bar{1}1)$ was quite large and very strongly striated parallel to its combination edge with the cube. The faces gave no reflection but were measured by covering them with glass plates and then measuring on the cube. This was repeated twice, giving $24^{\circ} 49'$, $25^{\circ} 21'$, calculated $25^{\circ} 14'$.

In appearance the crystals resemble very closely those of sphalerite, while the forms which are common to both are $a(100)$, $o(111)$, $o'(1\bar{1}1)$, $\omega(511)$, and $m(311)$.

NOTE. The second portion of this article relating to Metacinnabarite is here omitted.—EDITOR.

GERHARDTITE AND ARTIFICIAL BASIC CUPRIC NITRATES.

By H. L. WELLS AND S. L. PENFIELD.

(From Amer. Jour. Sci., 1885, vol. 30, pp. 50-57.)

WE shall describe in the present article a natural, crystallized basic cupric nitrate and a crystallized artificial salt of the same chemical composition but of different crystalline form. We also give an account of a reinvestigation of two basic cupric nitrates to which have been ascribed different compositions, but which, as we shall show, have the same composition as the basic nitrates described by us and by other investigators, whose results will be briefly summarized.

GERHARDTITE, *a new mineral*.

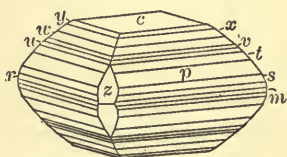
This mineral was first identified as a new species by Professor Brush, who found it among a lot of copper minerals from the United Verde Copper Mines, Jerome, Arizona, which were left at the Sheffield Scientific School by Mr. G. W. Stewart, assayer, from that place.

The single specimen in our possession consists of a small piece of very pure massive cuprite, along a crack in which the crystals of the nitrate occur, together with acicular crystals of malachite. The crystals, 4-6 mm. in diameter, were few in number and were almost wholly sacrificed to obtain material for investigation. An attempt has been made to obtain more of the material, but as yet no other specimens have been received, although we are in hopes that more may be found at the locality. From the abundance of crystals on the specimen in our possession, it would seem that there must have been a quantity of it found. It was probably regarded as malachite by the miners. Another specimen contains crystals of atacamite on the cuprite.

The crystals, which were carefully separated from the cuprite, were subjected first to crystallographic, then to chemical examination. About 0.8 of a gram was obtained almost perfectly pure, the only impurity being a few acicular crystals of malachite which sometimes penetrated the nitrate but were visible only under the microscope.

The hardness of the mineral is 2. Specific gravity, 3.426. Color dark-green. Streak light-green. Transparent.

The crystals after being detached were only fragmentary. All those suitable for measurement were reserved. They were very fragile and had to be separated and handled with very great care. The crystals are orthorhombic, having the habit shown in the accompanying figure. There are two cleavages, which serve for orientation, one basal, parallel to c , as perfect as the most perfect cleavage of gypsum, a second, less perfect, parallel to the micropinacoid. The crystals can be readily bent, in which case they crack and separate along the latter direction. The most prominent forms on the crystals, besides the basal plane, are a series of pyramids occurring in oscillatory combination, which makes their identification somewhat difficult. The best measurements were obtained from a small but very perfect macrodome which was found on two crystals. Owing to the fragmentary nature of the crystals and the difficulty of identifying the pyramidal planes, their orthorhombic form might be doubted were it not for their optical properties.



The axial ratio was obtained from the following measurements:

$$c \wedge z \ 001 \wedge 201 = 68^\circ 16' 00''$$

$$z \wedge p \ 201 \wedge 111 = 39^\circ 3' 30''$$

giving

$$a : b : c = 0.92175 : 1 : 1.1562$$

The following forms were observed:

c , 001	r , 551	t , 778	w , 223
z , 201	s , 221	u , 334	x , 13.13.20
m , 110	p , 111	v , 7.7.10	y , 112

The following is the table of measured and calculated angles, the measurements being made on eight crystals, the number of times each form was measured being given.

		Calculated.	Measured.	No. of times.
$m \wedge m$	110 $\wedge$ 1 $\bar{1}$ 0	85° 20'		
$z \wedge z$	201 $\wedge$ 20 $\bar{1}$	43° 28'	43° 34'	1
$c \wedge m$	001 $\wedge$ 110	90° 00'	90° 15'–90° 25'	2
$c \wedge r$	001 $\wedge$ 551	83° 19'	83° 1'	1
$c \wedge s$	001 $\wedge$ 221	73° 40'	73° 53'	1
$c \wedge p$	001 $\wedge$ 111	59° 37'	59° 23'–59° 57'	6
$c \wedge t$	001 $\wedge$ 778	56° 11'	55° 57'–56° 19'	3
$c \wedge u$	001 $\wedge$ 334	51° 59'	51° 52'–52° 20'	2
$c \wedge v$	001 $\wedge$ 7.7.10	50° 3'	49° 46'–50° 38'	3
$c \wedge w$	001 $\wedge$ 223	48° 40'	48° 8'–49° 12'	8
$c \wedge x$	001 $\wedge$ 13.13.20	47° 57'	47° 11'–47° 56'	5
$c \wedge y$	001 $\wedge$ 112	40° 28'	40° 13'–40° 18'	2
$x \wedge x$	13. 13. 20 $\wedge$ 1 $\bar{3}$.13.20	60° 27'	60° 9'	1

Only distinct reflections were recorded, though other forms seemed to be present but were not definite enough to be determined. The variation in the measurements is large and may be due in part to an accidental bending of the crystals. The forms x and v with improbable indices would have been regarded as accidental had they not occurred repeatedly giving very distinct reflections.

Tabular fragments parallel to the basal cleavage, show under the polarizing microscope an extinction parallel to the macro-diagonal cleavage lines, and in convergent light a bisectrix normal to c , 001. The optic axes lie in the brachypinacoid. The axial angle is large and could not be measured in air. Measured in the heavy solution of HgI_2 in KI ($n = 1.703$ for yellow, 1.722 for green):

$$2H = 76^\circ 20' \text{ for yellow.}$$

$$2H = 80^\circ 4' \text{ for green.}$$

$$\text{Dispersion } \rho < v.$$

A very thin section had to be used to obtain the character of the dispersion, as moderately thick sections were practically opaque to yellow light. The indices of refraction could not be determined owing to the want of suitable material, the Kohlrausch Totalreflectometer giving no total reflection.

Double-refraction is strong, negative.

Pleochroism is distinct:

For vibrations parallel to τ (that is a), blue.

For vibrations parallel to η (that is b), green.

For vibrations parallel to α (that is c), green.

Chemical composition. — Qualitative examination showed only the presence of CuO , N_2O_5 and H_2O . An analysis by Wells gave the following results:

- I. 0.3975 gram yielded 0.0457 H_2O and 0.2634 CuO .
 II. 0.3986 gram yielded 0.0449 H_2O , 0.2646 CuO , and 19.7 c.c. dry N at 12.8° and 759 mm. (cor.).

	I.	Found.	II.	Calculated for $4\text{CuO} \cdot \text{N}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$.
H_2O	11.49		11.26	11.56
CuO	66.26		66.38	66.22
N_2O_5	22.25*		22.76	22.52
	100.00		100.40	100.00

Pyrognostics, &c. B. B. fuses at 2, coloring the flame green. With soda on coal easily reduced to metallic copper with deflagration. In closed tube gives nitrous fumes and water which reacts strongly acid. Soluble in dilute acids, insoluble in water.

It is somewhat surprising that a mineral of this composition has not been found before, owing to the occurrence of nitrates in natural waters, the stability and insolubility of the compound, and the ease with which it is made artificially.

We propose for this beautiful and unique mineral, the only insoluble nitrate yet found in nature, the name Gerhardtite from the chemist who first determined the true composition of the same compound † made artificially.

NOTE. — The description of crystallized artificial basic cupric nitrate is here omitted. — EDITOR.

* By difference.

† Jour. Pr. Chem., xxxix, 136.

ON THE CHEMICAL COMPOSITION OF HERDERITE.

By S. L. PENFIELD AND D. N. HARPER.

(From Amer. Jour. Sci., 1886, vol. 32, pp. 107-110.)

THE rare material for carrying on the present investigation of herderite was given to us by Mr. L. Stadtmüller and Professor George J. Brush. The crystals were carefully picked by hand and freed as far as possible from all foreign matter. They were then crushed and sifted and suspended in the Thoulet solution; only the material whose specific gravity was greater than 2.95 was used for analysis. By this means there was separated from the hand-picked crystals a little questionable material, which was used in making a sort of preliminary analysis, and we were able to obtain over five grams of very pure material. Before making the separation with the Thoulet solution we carefully took the specific gravity of some of the purest crystals by taking the specific gravity of the solution in which they were suspended without floating or sinking. This we found to be from 3.012 to 3.006, the heaviest being the specific gravity of a very clear transparent crystal, while the more opaque and cracked crystals were a trifle lighter. The mineral is so much heavier than the quartz and feldspar to which the crystals were attached, that we feel very confident of the purity of the material which we analyzed.

The analysis was made after we had had considerable experience in the determination of beryllium and had made some experiments in determining it in presence of phosphoric acid. The method which we adopted gave good satisfaction, and we give it here somewhat in detail. The mineral was dissolved in nitric acid, the solution concentrated to a small

volume, sulphuric acid was added, and the gypsum crystals, after being collected by filtering through a rubber funnel, were ignited and weighed as CaSO_4 . The filtrate was concentrated in a platinum dish and gently ignited to drive off all hydrofluoric acid and the excess of sulphuric acid. The residue was dissolved in hydrochloric acid, a basic acetate precipitation of a part of the beryllium and phosphoric acid was made in the cold with ammonium acetate, and a little calcium precipitated from the acetic acid filtrate by ammonium oxalate, which was ignited and weighed as CaO . The beryllium in the filtrate from calcium oxalate was precipitated as a phosphate by means of ammonia, filtered, and the phosphoric acid in the filtrate precipitated with magnesia mixture. The two precipitates containing the beryllium as phosphate (the basic acetate precipitate contained the bulk of the beryllium) were ignited in the same crucible and fused with sodium carbonate. The fused material was soaked out in water, phosphoric acid obtained in the solution by the usual method, while the insoluble beryllium oxide was dissolved in hydrochloric acid, precipitated with ammonia, weighed, and the trace of P_2O_5 contained in it separated with ammonium molybdate. The P_2O_5 and bases in Analysis III, on which we place the greatest confidence, were separated and determined in the above manner.

Other determinations are given to show the accuracy of the method. The CaO in II was all obtained in the filtrate from the basic acetate precipitation and was not partially precipitated as gypsum. The BeO in the same analysis was tested for Al_2O_3 , but not more than a questionable trace could be detected. The P_2O_5 in I was from a direct determination with ammonium molybdate, but a very slight mechanical loss was incurred. The fluorine was determined in III by driving off the silicon fluoride and titrating the hydrofluosilicic acid by means of a standard alkali.* After making the determinations, fresh U-tubes were connected with the apparatus and the aspiration carried on for several hours, but no more

* *Am. Chem. Jour.*, i, 27.

silicon fluoride was driven off. As our alkali had just been standardized by means of sodium carbonate and test experiments on fluor spar, we feel very confident that the fluorine determination is correct. The water determinations are somewhat surprising. Mackintosh * made no tests for water, and considered the mineral to be an anhydrous phosphate with fluorine. Winkler † made no determination of fluorine and obtained no satisfactory tests for that element by etching glass. He obtained a loss by ignition, however, of 6.59 per cent in the Stoneham mineral by strong ignition, which he regards as water. Genth ‡ obtained 6.04 per cent of fluorine by direct determination, and 0.61 per cent of water by heating the mineral with lead oxide to bright redness. Mackintosh § obtained good tests for fluorine by etching, and found a loss of 6.03 per cent by strong ignition. He proved conclusively that fluorine was given off by strong ignition, and concludes that it is replaced in part at least by oxygen. We are scarcely willing to believe that such a reaction would take place on heating an anhydrous phosphate containing fluorine. Our first water determination was made by weighing out the mineral in a boat, placing it in a combustion tube containing a layer of dry sodium carbonate, igniting the tube to full redness and collecting the water in a weighed chloride of calcium tube. We obtained 0.69 per cent; afterward the mineral was dissolved, and analysis II completed from the same material. After almost completing our analysis and finding only 5.27 per cent of fluorine we tried the following experiments. A little herderite powder was heated in a closed tube of hard glass; at first only a slight film of water condensed in the cold part of the tube; by strong ignition over the blast lamp, however, there was a sudden evolution of hydrofluoric acid, which etched the glass very perceptibly near the mineral and deposited a film of silica and very acid water, as marked

* Amer. Jour. Sci., 1884, vol. 27, 135.

† Neues Jahrbuch für Mineralogie, 1884, ii, 134.

‡ Proc. Amer. Phil. Society, xxi, 1884, 694.

§ Amer. Jour. Sci., 1884, vol. 28, p. 401.

as in an ordinary reaction for fluorine in a closed tube with acid sulphate of potash. In our experience we have never seen any hydrous fluoride which gives off such strongly acid water and such a marked fluorine reaction. Some of the powdered mineral was placed in a closed glass tube, covered with a layer of dry sodium carbonate and strongly ignited; neutral water was given off and condensed as a ring, which indicated more than a trace of water. The water was obtained in the following way. About two grams of calcite were ignited over the blast lamp till a constant weight was obtained. The mineral was then weighed into the same crucible, the lime was slaked with water, the contents of the crucible were carefully dried and then ignited till constant weight was obtained, the water being calculated from the loss of weight. The slaking of the lime makes an intimate mixture of the mineral with the lime, and a preliminary experiment proved to us that only neutral water was driven off. In I there was a slight mechanical loss in slaking the lime, which caused the water determination to be too high, the P_2O_5 too low. In III the water was obtained from a larger quantity of mineral. No sublimate was formed on the cover of the crucible by the volatilization of any fluoride. The analyses were made on air-dry powder which lost 0.10 per cent by drying for one hour at 100° C. The beryllium precipitates were always of a light cream color after ignition, indicating that not more than a minute trace of iron was present.

The following quantities of mineral were used in making the analyses: I, 0.4552 grams; II, 1.0029; III, P_2O_5 and bases 0.7336, F. 0.9692, H_2O 1.1612.

	I.	II.	III.	Ratio.	Calculated.	
P_2O_5	43.47	...	43.74	0.308	1.00	43.83
BeO	...	15.23	15.51	0.620	2.01	15.44
CaO	...	33.61	33.67	0.601	1.95	34.57
F	...	...	$5.27 \div 38$	0.138	0.343	5.86
H_2O	4.37 ?	...	3.70	0.205		2.77
			101.89		1.11	102.47
O equivalent of F	...		2.22			2.47
			99.67			100.00

The ratio of $P_2O_5 : BeO : CaO : (F_2 + H_2O) = 1 : 2 : 2 : 1$ nearly. The high temperature at which the water is driven off indicates that it is not water of crystallization, but is very firmly united in the mineral as hydroxyl. Every H_2O represents two hydroxyl groups, and the OH is isomorphous with F. The ratio of F : OH is nearly 1 : 1, or more nearly 3 : 4 in our analysis. In the calculated analysis we have used the ratio F : OH = 1 : 1, but recognize that it is probably simply a case of isomorphism. The composition of herderite is, therefore, an isomorphous mixture of $CaBeFPO_4$ with $CaBe(OH)PO_4$. This may be written $CaBe(F,OH)PO_4$, or a salt of phosphoric acid, two of whose hydrogen atoms have been replaced by a bivalent element, and the third likewise by a bivalent element whose other free affinity has been satisfied by a fluorine atom or hydroxyl. This is the same composition as that proposed by Mackintosh, except that he regarded the mineral as simply the fluorine compound and did not detect the water. Chemically herderite is closely related to the three minerals — wagnerite, triplite, and triploidite, whose compositions are respectively Mg_2FPO_4 , $(Fe,Mn)_2FPO_4$ and $(Fe,Mn)_2(OH)PO_4$. These three minerals offer the best illustration we have of the isomorphism of F and OH, and we feel that we have in herderite another strong proof of the correctness of this interesting relation.

ON THE CHEMICAL COMPOSITION OF RALSTONITE.

By S. L. PENFIELD AND D. N. HARPER.

(From Amer. Jour. Sci., 1886, vol. 32, pp. 380-385.)

A NUMBER of years ago Professor George J. Brush generously gave one of us a specimen containing a large amount of the rare mineral ralstonite associated with thomsenolite from Arksuk-fiord, Greenland. Considerable time was spent in picking out the octahedral crystals free from thomsenolite, and only a partial analysis was made which was never published; difficulty was found in determining the fluorine, and the material was exhausted before a complete analysis was made. The results were essentially the same as those of Nordenskiöld.* Since then J. Brandl† has analyzed the mineral, using material which was selected by Professor P. Groth. The results of the three analyses are as follows:

	Nordenskiöld.	Penfield.	Brandl.
Mg	5.52	4.29	3.56
Na	5.66	4.12	5.50
K	tr.	0.11	...
Ca	1.99	1.67	1.53
Al	22.94	22.33	22.14
H ₂ O	14.84	18.41	10.00
F	...	...	57.12
	49.95		99.85

Only small quantities were used in making the above analyses owing to the scarcity of material and the difficulty of obtaining it free from thomsenolite. As far as the metals are concerned, the three analyses agree remarkably well with

* Geol. Fören. i Stockholm. Förhandl., 1874, ii, 81.

† Annalen der Chemie, ccxiii, 7.

one another. Nordenskiöld calculated that the 50.05 per cent of material which was not determined in his analysis, if assumed to be fluorine would not be sufficient to satisfy all the metals, and concludes that the mineral must contain some oxygen. The same would be true in Penfield's analysis. Brandl determined the fluorine directly and found it just sufficient to satisfy the metals; he proposed the formula $3(\text{Na}_2, \text{Mg}, \text{Ca})\text{F}_2 \cdot 8\text{AlF}_3 \cdot 6\text{H}_2\text{O}$.

The fragments which were left after selecting material for the above analysis by Penfield were carefully saved, and although we could see that they contained large quantities of ralstonite, still it was found impossible to separate the pure mineral from thomsenolite by hand picking. After selecting the purest crystal of ralstonite we could find, we took its specific gravity by just floating it in the Thoulet solution and found it to be 2.560; by the same method we found the specific gravity of cryolite to be 2.974 and thomsenolite 2.979. The great difference in specific gravity between ralstonite and the other two minerals admits of a very perfect separation by means of the Thoulet solution. All the material which we had was crushed and made to pass an eighty-mesh sieve, the finest dust was washed away by means of water and the separation carried on as usual, repeating it several times so as to remove the last traces of thomsenolite. Finally, the purest powder was floated on a solution whose specific gravity was 2.611, a few heavier particles were removed and the solution diluted to the specific gravity 2.551, when all but a trace of the powder sank to the bottom. This material, amounting to over twelve grams, showed no impurity of double refracting thomsenolite when examined under the polarizing microscope, and was used in making the following analysis.

A few remarks are necessary regarding the method of analysis. It was found to be practically impossible to decompose the mineral completely with sulphuric acid; a residue was always left which could not be dissolved by further treatment with sulphuric acid, nor with hydrochloric or nitric

acids. For the determination of the metals the mineral was fused with sodium carbonate, the fusion soaked out with water, sulphuric acid was added, and the solution evaporated and ignited till the hydrofluoric and excess of sulphuric acids were expelled. The mass was then dissolved in water and the metals determined according to the usual methods. Sodium was determined once by Smith's fusion method, and again by decomposing the mineral as far as possible with sulphuric acid, assuming that the sodium was all in solution and the insoluble portion some compound of aluminum. Water was determined by igniting the mineral in a combustion tube, passing the vapor over dry sodium carbonate and collecting it in a weighed chloride of calcium tube. The fluorine could not be determined by driving off the silicon fluoride. About twenty-five per cent of fluorine was readily driven off; by continuing the decomposition with the temperature of the sulphuric acid about 160° , silicon fluoride was slowly, but in the course of six or eight hours never completely given off. The greatest amount of fluorine which we were able to drive over by this method was about thirty-one per cent. This is not at all in accordance with the statement of Brandl,* who states that the decomposition commences at 145° and is completed at 160° . We found it impossible to make a determination according to the method described by him. Our determinations are made according to the Berzelius method by fusing with mixed potassium and sodium carbonates and silica. They are probably too low by about one-half to one per cent, judging from test experiments which we made on cryolite. Our determinations are as follows:

			Mean.	Ratio.		
Mg	4.46	4.31	4.39	0.183	} 0.278	1.00
Na	4.25	4.27	$4.26 \div 46$	0.093		
K	0.12	0.12	$0.12 \div 78$	0.002		
Ca	0.03	. . .	0.03			
Al	24.23	24.27	24.25	0.882		3.17
F	39.76	40.05	39.91	2.101		7.56
H ₂ O	18.72	18.74	18.73			
			91.69			

* Loc. cit.
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The ratio of $(\text{Mg}, \text{Na}_2, \text{K}_2) : \text{Al} = 1 : 3$ nearly. This ratio being assumed as correct, the ratio of the fluorine necessary to unite with the metals should be 11, whereas we only find 7.56. The fluorine is therefore not sufficient to unite with the metals, and this is fully in accordance with the suggestion of Nordenskiöld. If the metals in our analysis, which are in excess of the fluorine, are united to hydroxyl, which, as has been shown to be the case in several instances, is capable of replacing fluorine, it would be necessary to have 16.27 per cent of hydroxyl, corresponding to 8.61 per cent of water, in order to make the ratio $(\text{Mg}, \text{Na}_2, \text{K}_2) : \text{Al} : (\text{F} + \text{OH}) = 1 : 3 : 11$; the remaining 10.12 per cent of water would then be regarded as water of crystallization, and would correspond to two molecules, making the formula of the mineral $(\text{Mg}, \text{Na}_2)\text{Al}_3(\text{F}, \text{OH})_{11} \cdot 2 \text{H}_2\text{O}$. Making this disposition of the water, our analysis would be:

		Ratio.		
Mg	4.39	0.183	} 0.278	1.00
Na	$4.27 \div 46 = 0.093$			
K	$0.12 \div 78 = 0.002$			
Ca	0.03			
Al	24.25	0.882		3.17
F	39.91	2.101	} 3.058	11.00
OH	16.27	0.957		
H ₂ O	10.12	0.562		2.02
	<u>99.36</u>			

It will be seen that the assumption that hydroxyl replaces fluorine not only makes up for the deficiency in the analysis but also leads to a very satisfactory ratio. This assumption is also well supported by actual experiment. When the mineral is cautiously heated in a closed glass tube, at first neutral water, by stronger ignition acid water, is driven off. The first that comes off is undoubtedly water of crystallization, afterwards the hydroxyl is decomposed and fluorine comes off in combination with the hydrogen. By heating the air-dry powder at 100° C. there is a loss of only 0.10 per cent; by heating in an air bath to a temperature never exceeding 250°

C. the mineral lost 10.37 per cent, the water going out very slowly; the experiment was carried on for over a week, during the last three days of which the weight remained very constant. If this 10.37 per cent is regarded as water of crystallization, the remaining 8.36 per cent would correspond to 15.78 per cent of hydroxyl, which agrees closely with the figures in our recalculated analysis. The ratio of $\text{Mg} : \text{Na}_2$ is almost exactly 2 : 1, there seems to be no simple ratio between F and OH. The excess of the aluminum in the analysis may be owing to some slight impurity. We have never seen perfectly transparent glassy crystals of ralstonite, and their turbidity may be owing to some slight decomposition; if this is the case the alkalis would naturally be most readily removed, causing the aluminum to be too high. If our fluorine determination should be as much as one per cent too low, which is probably not the case, our results would not be materially changed. Using the actual water of crystallization and hydroxyl determinations and determining the fluorine by difference, we would have for the latter part of our analysis:

		Ratio.		
F	40.79	2.147	} $3.075 \div 278$	11.06
OH	15.78	0.928		
H ₂ O	10.37			
			$0.576 \div 278$	2.07

Probably this determination of fluorine, by difference 40.79 per cent, represents the true amount of that element more closely than the results of our actual determinations.

Assuming, as it seems fair to do, that our results and conclusions are correct and that the formula which we have proposed is the true one, namely, that the mineral is an isomorphous mixture of $(\text{Mg}, \text{Na}_2)\text{Al}_3\text{F}_{11} \cdot 2\text{H}_2\text{O}$ and $(\text{Mg}, \text{Na}_2)\text{Al}_3(\text{OH})_{11} \cdot 2\text{H}_2\text{O}$, in which formulæ fluorine and hydroxyl play the same part or are isomorphous, let us see if we can in any way account for the variations in the previously published analyses, especially between Brandl's and our own, the only two complete analyses. First, we would emphasize that the greatest care was used in preparing the material for our

analysis; the extremes in the specific gravity of the powder which we separated were 2.611 and 2.551, or a variation between the lightest and heaviest of only 0.060. Second, our analysis shows that our material is practically free from calcium, indicating a very complete separation from thomsenolite with which the ralstonite is so intimately associated, and showing that calcium is not an essential constituent of the mineral. Third, we were not limited regarding the amount of material which we could use, as we had an abundant supply of the pure mineral. From the same specimen from which our material was derived, one of us by very careful picking was able to obtain nearly one gram of octahedral crystals, which were supposed to be pure, but which, as is shown in the analysis near the beginning of this article, contained 1.67 per cent of calcium. This indicates that a most careful and laborious hand-picking had not been sufficient to free the small crystals wholly from thomsenolite from which the calcium was unquestionably derived. It seems highly probable that other investigators have worked with material containing slight quantities of thomsenolite. Groth,* for instance, states that the material which he furnished to Brandl for analysis showed under the polarizing microscope particles of a strongly double refracting mineral with quadratic habit which was unquestionably thomsenolite. If we assume that the mineral is free from calcium, as our analysis indicates, and that the calcium in the other analyses is all derived from thomsenolite, we should find by calculation the following figures (see p. 149), giving the per cent of thomsenolite in the analyzed material and of the mineral free from thomsenolite.

In these analyses the ratio $(\text{Mg} + \text{Na}_2) : \text{Al} = 1 : 3$, very nearly, especially considering the small quantity of mineral which was used in making the analyses. In Brandl's analysis, the only complete one, the fluorine is just sufficient to satisfy the metals, while the ratio $(\text{Mg} + \text{Na}_2) : \text{Al} : \text{F} : \text{H}_2\text{O} = 0.97 : 3 : 10.88 : 2.02$, or nearly $1 : 3 : 11 : 2$, the same as required by the formula proposed by us. In this case, however, the

* Zeitschr. Kryst., vii, 474.

	Nordenskiöld.	Penfield.	Brandl.	Calculated for (Mg,Na ₂)Al ₃ F ₁₁ · 2H ₂ O.
Thomsenolite	11.07	9.28	8.51	. . .
Mg	6.20	4.29	3.90	4.46
Na	3.95	4.27	5.05	4.27
Al	24.27	21.19	23.06	22.99
F	. . .	. . .	57.68	58.25
H ₂ O	15.68	19.46	10.17	10.03
			99.85	100.00

$$\left. \begin{array}{l} \text{Ratio of} \\ (\text{Mg,Na}_2) : \text{Al} \end{array} \right\} = 1.17 : 3 \quad 1.06 : 3 \quad 0.97 : 3$$

material is a pure fluorine compound, containing no hydroxyl. Following Brandl's analysis we have given the percentage composition calculated from the above ratio in which the $\text{Mg} : \text{Na} = 1 : 1$. It will be noticed how closely the figures agree with the analysis of Brandl.

The great difference in the proportion in which the metals are united $(\text{Mg} + \text{Na}_2) : \text{Al} = 1 : 3$ in ralstonite and $\text{Ca} : \text{Na} : \text{Al} = 1 : 1 : 1$ in thomsenolite, would account for the decided change in the formula derived from an analysis of a mixture of ralstonite with a little thomsenolite. Brandl's formula, $3(\text{Na}_2, \text{Mg, Ca})\text{F}_2 \cdot 8\text{AlF}_3 \cdot 6\text{H}_2\text{O}$, is therefore a little too low in AlF_3 . The difference in the deportment of the mineral when treated with strong sulphuric acid may be owing to the fact that, although the fluorine compound is readily decomposed by that acid so that Brandl was able to determine the fluorine by driving over SiF_4 , the hydroxyl compound in our mineral in some way hinders the decomposition of the fluorine compound, perhaps by being in itself with difficulty decomposed, and inclosing and thus protecting some of the molecules of the fluorine compound from decomposition.

In thin sections under the microscope all of the ralstonite appears very transparent and free from visible inclusions and decomposition products. Some of the crystals on the original specimen were colored yellow, and where one of these had been cut through, the yellow substance was seen to consist of a very thin film, probably of iron oxide, coating the crystal. The larger crystals were zonal in structure, the zones lying parallel

to the faces of the octahedron. This zonal structure is scarcely perceptible in ordinary light, being indicated by faint grayish streaks running parallel to the contours of the cross section, which could not be resolved by the use of high powers into visible inclusions. In polarized light the zonal structure was more perceptible; all of the crystals show slight double refraction and a division of the cross sections into fields reminding one of the double refraction of analcite. The slightly double refracting ralstonite with its absence of cleavage is in marked contrast to the strongly double refracting thomsenolite, showing brilliant polarization colors, blue of the second order, distinct cleavage and inclined extinction.

In closing we wish to express our thanks to Professor Brush for his liberality in providing us with the rare material for carrying on this investigation.

SPERRYLITE, A NEW MINERAL.

By HORACE L. WELLS.

(From Amer. Jour. Sci., 1889, vol. 37, pp. 67-70.)

A SMALL quantity of the remarkable mineral which is the subject of this article was sent to the writer in October of the present year by Mr. Francis L. Sperry of Sudbury, Ontario, Canada, chemist to the Canadian Copper Co. of that place. A few tests sufficed to show that it was essentially an arsenide of platinum and consequently of great interest, since platinum has not been found before, at least as an important constituent, in any minerals except the alloys with the other metals of the platinum group.

Since the time mentioned, Mr. Sperry has furnished, with great liberality, an abundance of the material for investigation, and has given the following account of its occurrence:

"The mineral was found at the Vermillion Mine in the District of Algoma, Province of Ontario, Canada, a place 22 miles west of Sudbury and 24 miles north of Georgian Bay, on the line of the Algoma Branch of the Canadian Pacific Railway. The mine was discovered in October, 1887, and a 3 stamp mill was put up for the purpose of stamping gold quartz. Associated with this gold ore are considerable quantities of pyrite, chalcopyrite, and pyrrhotite, and, at the contact of ore and rock and occupying small pockets in decomposed masses of the ore, there is a quantity of loose material composed of gravel, containing particles of copper and iron pyrites. It was in milling this loose material that several ounces of the arsenide of platinum were gathered on the carpet connected with the stamp-mill. Through the kindness of Mr. Charlton, the genial President of the Vermillion Mining Co., all of the

mineral that was available was generously placed at my disposal."

It may be mentioned here that Mr. Sperry sent me, a few weeks before sending the arsenide, a minute bead which he had obtained in making a fire-assay for gold on an ore, consisting chiefly of chalcopyrite and pyrrhotite, which came from the same mine where the arsenide was found, but which was not the material in which it actually occurred. This bead on examination proved to be composed largely of metals of the platinum group, and, from the color of the precipitate produced by ammonium chloride, it was thought that it contained a large proportion of iridium, but its small size prevented a satisfactory examination. With this bead in mind, I expected that the new mineral would contain a considerable amount at least of iridium, but, strangely enough, none of this metal was found in it. The material as received consisted of a heavy, brilliant sand composed largely of the arsenide; but intermixed with this a considerable amount of fragments of chalcopyrite, pyrrhotite and some silicates could be seen. In order to purify the substance it was treated for a short time with warm aqua regia to remove sulphides, etc.; then it was treated for a long time with hot hydrofluoric acid to remove the silicates. After these treatments the sand possessed great brilliancy, but it was found by microscopic examination to contain some transparent grains which on chemical examination proved to be stannic oxide. Prof. S. L. Penfield kindly examined these grains and found that they corresponded perfectly in their optical properties with cassiterite.

Nearly all the grains of the new mineral showed extremely brilliant crystal faces, though most of the crystals were fragmentary; in size they were mostly between 0.05 and 0.5 mm. ($\frac{1}{200}$ and $\frac{1}{20}$ inch) in diameter.

The color of the mineral is nearly tin white or about the same as that of metallic platinum; the fine powder is black.

The specific gravity taken twice on the same 8 grams of material, was 10.420 and 10.424 at 20°; this material was the same that was used for analysis, and, correcting the average

of these results for 4.62 per cent of cassiterite, the true specific gravity becomes 10.602.

The sand is not easily wet by water and shows a marked tendency to float when brought to its surface. By placing a shallow layer of water upon the mineral in a vessel it is easy to nearly cover the surface of the water with a continuous layer of the crystals by inclining the vessel repeatedly so that they are brought to the surface. This phenomenon is not due to any oily substance upon the particles, for they float with equal readiness after being boiled with a strong solution of potash and washed with alcohol and ether. When they are floating upon water it is quite difficult to cause them to sink, and when carried to the bottom by a stream of water they frequently carry down small bubbles of air which they completely surround and hold down by their weight. If ether is poured upon water on which they are floating, they remain suspended between the two liquids, and, by agitation, can frequently be made to sink to the bottom in spherical clusters surrounding globules of ether.

The mineral is only slightly attacked by aqua regia; even when it is very finely pulverized and the strongest aqua regia is repeatedly applied with the aid of heat for several days, the solution is only partial.

Pyrognostics. — The mineral decrepitates slightly when heated. In the closed tube it remains unchanged at the fusing-point of glass. In the open tube it gives very readily a sublimate of arsenic trioxide and does not fuse if slowly roasted, but if rapidly heated it melts very easily after losing a part of the arsenic. Perhaps its most characteristic reaction is the following: when dropped on a red-hot platinum foil it instantly melts, gives off white fumes of arsenic trioxide having little or no odor, and porous excrescences are formed on the platinum which do not differ in color from the untouched foil.

Chemical analysis. — The following analyses of the mineral were made after a considerable amount of preliminary work had been done on it, the results of which confirm these figures.

	I.	II.	Mean.	Ratio.
As	40.91	41.05	$40.98 \div 75 = 0.546$	} $0.550 = 2$
Sb	0.42	0.59	$0.50 \div 122 = 0.004$	
Pt	52.53	52.60	$52.57 \div 197 = 0.267$	} $0.274 = 1$
Rh	0.75	0.68	$0.72 \div 104 = 0.007$	
Pd	trace	trace	trace	
Fe	0.08	0.07	0.07	
SnO ₂	4.69	4.54	4.62	
	99.38	99.53	99.46	

The composition is consequently represented by the formula PtAs₂, a small portion of the platinum and arsenic being replaced respectively by rhodium and antimony. In composition this mineral appears to be nearer Wöhler's laurite* than any other mineral now known. The form of both is isometric,† but their composition is apparently not quite analogous since the formula of laurite is given as RuS₂ + $\frac{1}{2}$ Ru₄Os. It is possible that the latter formula is slightly incorrect since Wöhler used an extremely small quantity (0.3145 gram) for his analysis and acknowledged the uncertainty of his results. It is also to be noticed that the composition of the mineral corresponds to that of the artificial platinum arsenide made by Murray.‡ The writer has confirmed the composition of this artificial arsenide by heating a known weight of platinum to redness and passing over it vapor of arsenic in a current of hydrogen. The following are the results of the experiments:

	Pt. taken.	As absorbed.	Ratio. Pt. As.
I	0.3806	0.2922	1 : 2.02
II	0.5725	0.4354	1 : 2.00
III	1.0657	0.8112	1 : 2.00

It was noticed in these experiments that the arsenic combines with the platinum with incandescence and the alloy melts even below a red heat after a part of the arsenic has been taken up. At the end of the operation, however, the fused globule solidifies, throws out peculiar arborescent forms and the PtAs₂ remains as a porous and very brittle mass

* Ann. Ch. Pharm., cxxxix, 116.

† See next article for crystalline form of Sperrylite.

‡ Watt's Dictionary.

which is neither fused nor changed in composition when heated to bright redness in hydrogen. In its behavior with solvents and its pyrognostic properties the artificial compound agrees exactly with the natural mineral.

Method of analysis. — The amount of substance taken for each analysis was about 1.5 g. The pulverized substance was gradually heated in a current of chlorine gas and the volatile chlorides were absorbed by water in a receiver.* This liquid was made ammoniacal, after adding a very small quantity of tartaric acid to keep the small amount of antimony in solution, and the arsenic was determined as magnesium pyroarsenate. From the filtrate from the ammonium magnesium arseniate, antimony and a trace of platinum were precipitated as sulphides, the sulphide of antimony was dissolved in strong hydrochloric acid, the sulphide was reprecipitated, filtered on asbestos and weighed after proper heating in a current of carbon dioxide, while the trace of platinum sulphide was ignited and the residue was added to the main part of the platinum left by treatment with chlorine. This part was treated with dilute aqua regia; this left an insoluble residue consisting of cassiterite and a finely divided black substance which had been found by previous qualitative tests to be rhodium. This residue was fused with sodium carbonate and sulphur, the insoluble rhodium sulphide formed was ignited in air, then in hydrogen and weighed, while the tin was determined as stannic oxide in the usual way. The purity of the rhodium was shown by its complete solubility in fused potassium bisulphate, also by finding that it gave no sodium double chloride soluble in alcohol after ignition with sodium chloride at a faint red heat in a current of chlorine. About $\frac{3}{8}$ of the total rhodium was found here. The purity of the stannic oxide was shown by reducing it in hydrogen and dissolving the metal in hydrochloric acid.

The solution in aqua regia containing platinum with a little

* Preliminary experiments with the artificial compound, PtAs_2 , had shown that all the arsenic passes off in this operation if the heat is applied slowly enough so that the substance does not melt after losing a part of its arsenic.

rhodium and iron and a trace of palladium was treated for the platinum metals essentially by the method of Claus; * the main variations being a repeated separation of platinum from rhodium and the weighing of platinum as metal. A distinct but extremely small precipitate of palladium cyanide was obtained, but the amount of palladium was too small to sensibly affect the balance when an attempt was made to weigh it.

The name. — The writer takes great pleasure in naming this interesting mineral after Mr. F. L. Sperry, to whose efforts this investigation is due.

* Rose und Finkener, Analytische Chemie, 6te Aufl., vol. ii, p. 236.

ON THE CRYSTALLINE FORM OF SPERRYLITE.

By S. L. PENFIELD.

(From Amer. Jour. Sci., 1889, vol. 37, pp. 71-73.)

THE crystalline form of sperrylite is isometric; pyritohedral. Simple cubes are common, octahedrons are exceptional, while the majority of the crystals, which are usually fragmentary, show combinations of cube and octahedron. The first crystal which was selected for measurement was a fragment showing the above mentioned combination; one of its central octahedral faces being imperfect, the best measurements were obtained from a cubic to an adjoining octahedral face. The results, which are given below, are very satisfactory considering the small size of the crystals, and prove that the mineral is isometric; it may also be said that where the reflections were sharpest and best the values came nearest to the theoretical.

		Calculated.
$a \wedge o$	$001 \wedge 111$	$54^{\circ} 34'$
$a \wedge o$	$001 \wedge 1\bar{1}1$	$54^{\circ} 44'$
$a \wedge o$	$100 \wedge 111$	$54^{\circ} 44'$
$a \wedge o$	$100 \wedge 1\bar{1}1$	$54^{\circ} 35'$
$a \wedge o$	$100 \wedge 11\bar{1}$	$54^{\circ} 45'$
$a \wedge a$	$100 \wedge 001$	$54^{\circ} 44'$
		90°

At first only the above mentioned forms were detected, but on sifting off the smallest crystals and carefully looking over the larger ones some were detected which suggested pyrite forms. The chemical relation of the mineral, $PtAs_2$, to the minerals of the pyrite group caused me to make a very careful search for pyritohedral forms, which was fortunately successful. Cubes with replacement of the edges are very exceptional; a number of them were found, however, and in

all cases the replacements, which were necessarily small and frequently failed on some of the edges, had the arrangement required by the combination of cube and pyritohedron. The best crystal selected for measurement was the top of a cube, measuring 0.35×0.45 mm., in combination with octahedron and two small but well developed pyritohedral faces; the latter gave very good reflections. The measured angles are

		Calculated.
001 $\wedge$ 102	26° 28'	26° 34'
001 $\wedge$ 102	26° 31'	26° 34'

Another crystal which was carefully measured was an irregular one measuring 0.35 and 0.55 mm. in two diameters; this was developed in all directions; in one zone the four cubic and four pyritohedral faces were all present in their proper order and gave satisfactory measurements, in a second zone four cubic and two pyritohedral faces were found and in the third zone four cubic and one truncating rhombic dodecahedral face were detected; this is the only case in which a dodecahedral (110) face was found. In a few cases the characteristic combination of octahedron and pyritohedron was detected, but the latter faces were always very small. These results are most satisfactory and from the number of crystals which have been examined and measured, in all of which the pyritohedral faces occur with their proper order and arrangement, the hemihedral nature of the mineral cannot be doubted. Some of the crystals are somewhat rounded and probably other isometric forms are present but none of them were determined. The faces on the crystals are usually very true and must possess a high polish to give such satisfactory measurements. It may also be noted that the cubic faces are not usually striated parallel to their intersection with the pyritohedron as is common in pyrite, although it was a slightly striated cube which first called attention to the pyritohedral nature of the crystals.

To sum up the crystallographic observations, the crystals usually show the combination of cube (100), octahedron

(111), pyritohedron (210), and very rarely dodecahedron (110). Taken in connection with the chemical results the mineral takes a place in our classification in the pyrite group where an atom of a metal, usually Fe, Co, or Ni is united with two atoms of either S, As, or rarely Sb, or an isomorphous mixture of them. As this is the first time that platinum has been found in combination in a mineral it may be noted that Fe, Co, and Ni and the metals of the platinum group fall in the same series in Mendelejeff's periodic system of the elements, which gives additional grounds for putting this mineral in the pyrite group.

The hardness of the mineral is between 6 and 7, which was determined by placing selected crystals on a bright feldspar surface, pressing down on them with a soft pine stick and rubbing back and forth; the sperrylite repeatedly cut into the feldspar but could not be made to scratch quartz. The crystals have no distinct cleavage but are very brittle and break with an irregular, probably conchoidal fracture.

RESULTS OBTAINED BY ETCHING A SPHERE AND CRYSTALS OF QUARTZ WITH HYDROFLUORIC ACID.

BY OTTO MEYER AND SAMUEL L. PENFIELD.

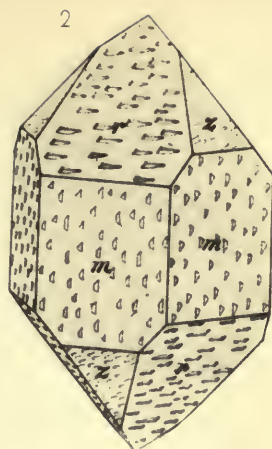
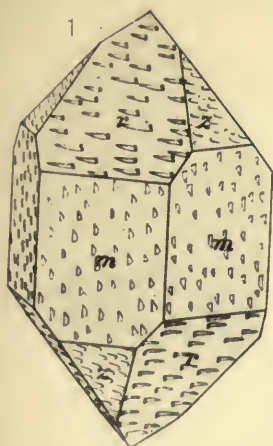
(From Transactions of Connecticut Academy, 1889, vol. 8, pp. 158-165.)

A FEW years ago one of us* published the results of an experiment of etching a sphere of calcite with acetic acid in which the symmetry of a calcite crystal was brought out by the character of the etchings on the sphere, and the final result of eating away the greater part of the calcite was a crystalline figure with rounded faces, but with a decided steep scalenohedral habit with truncations at the extremities of the vertical axis. This suggested to us the idea of trying similar experiments on spheres cut from other crystals. The difficulty, of course, lies in obtaining spheres of perfectly pure homogeneous material; the results furnish, however, an interesting and instructive means of studying the symmetry of any crystalline substance and as parts of the sphere are parallel to all possible faces of a crystal, as soon as the relation of the sphere to the axes of the crystal is made out the character of the etchings in any particular part of the sphere will determine the character of the etching produced by the solvent on any crystal face parallel to that particular part of the sphere. The ease with which spheres of Japanese quartz can be obtained and the readiness with which quartz yields in certain directions, to the action of hydrofluoric acid, made the following experiments quite easy, while the results, as will be seen, are far more striking than one would at first suppose.

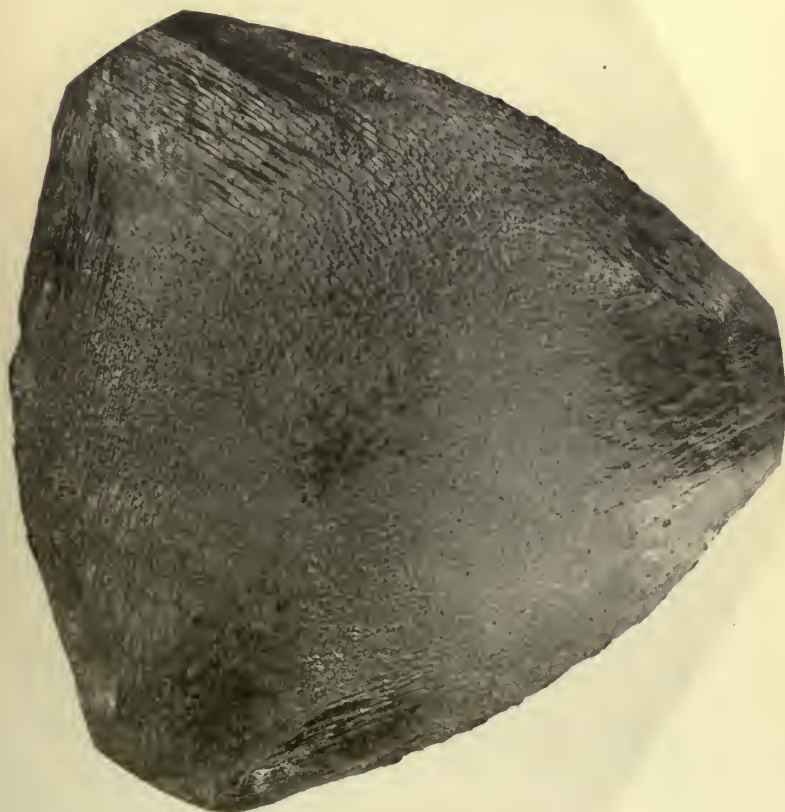
The results of our experiments will be better understood by reviewing some experiments made in 1855 by F. Leydolt † on

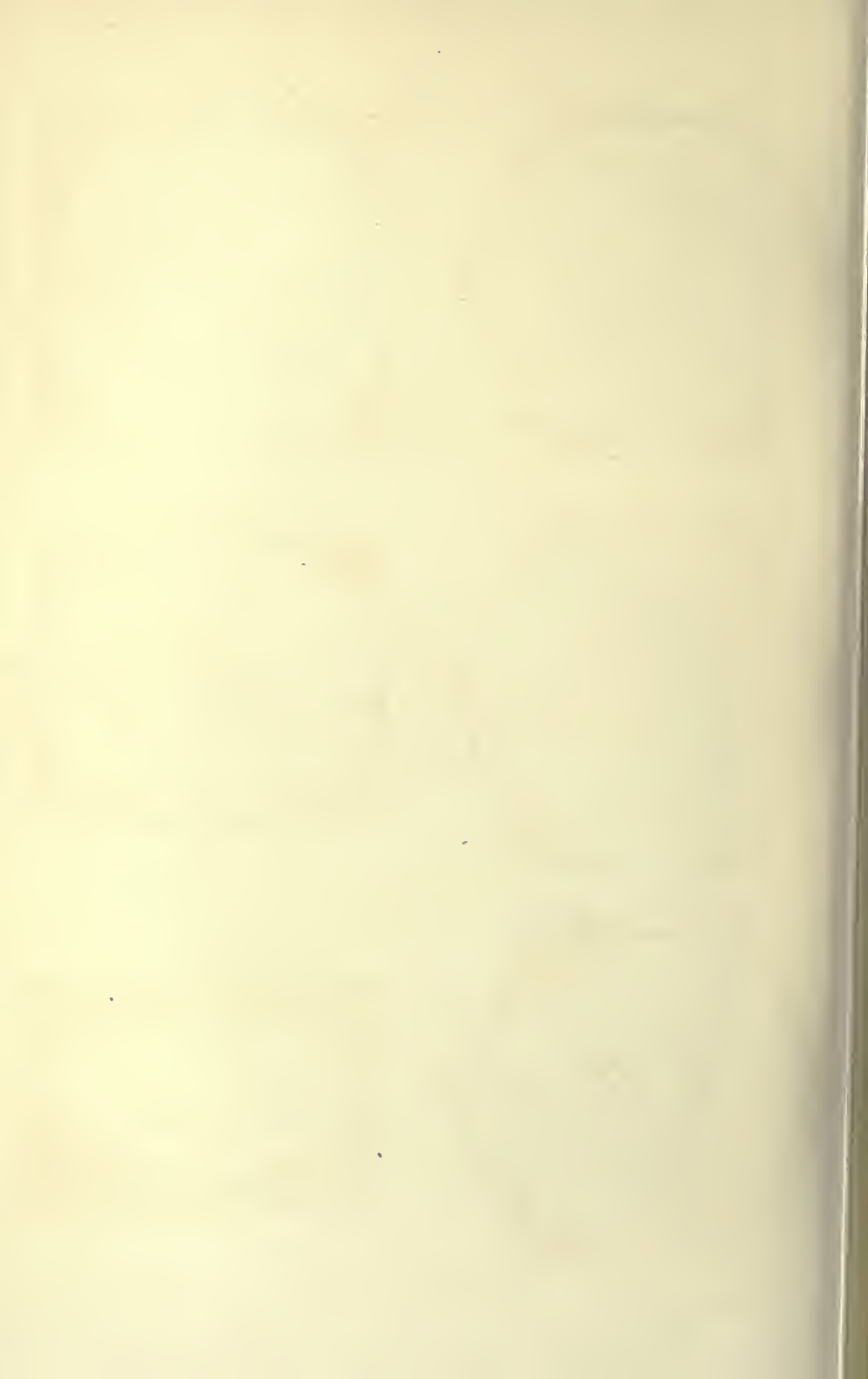
* Meyer, Jahrb. Minn., 1883; i, 74.

† Sitz-ber. der Wiener Akad., 1855, xv, p. 59.

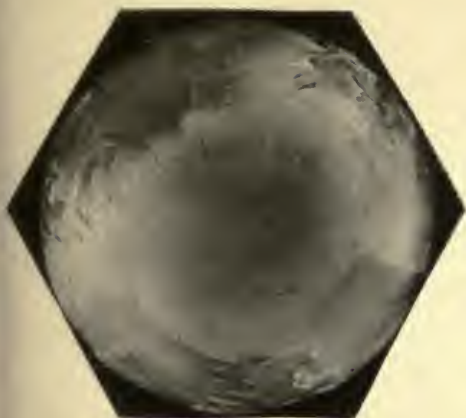


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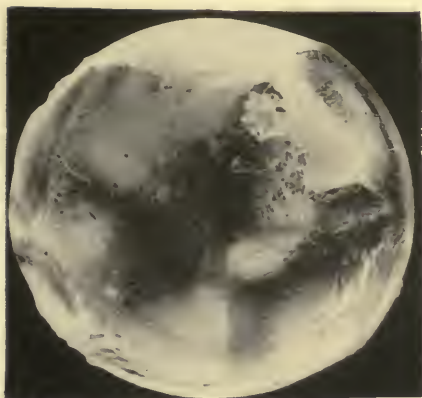




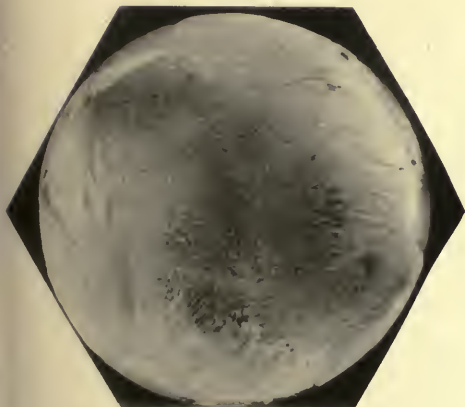
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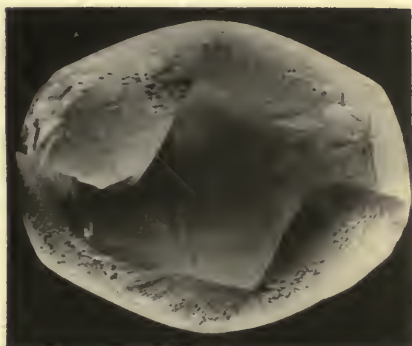
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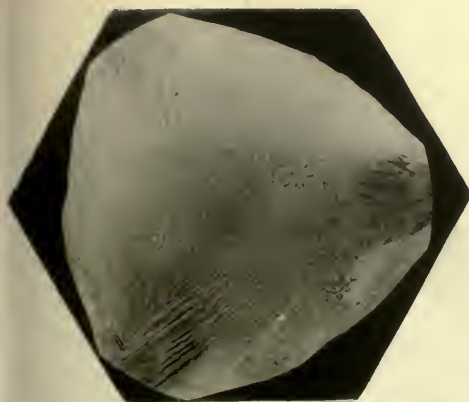
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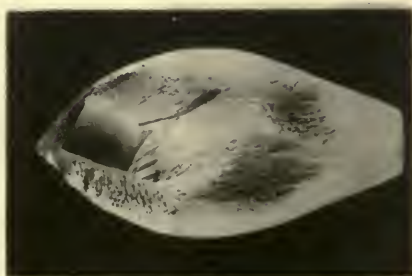
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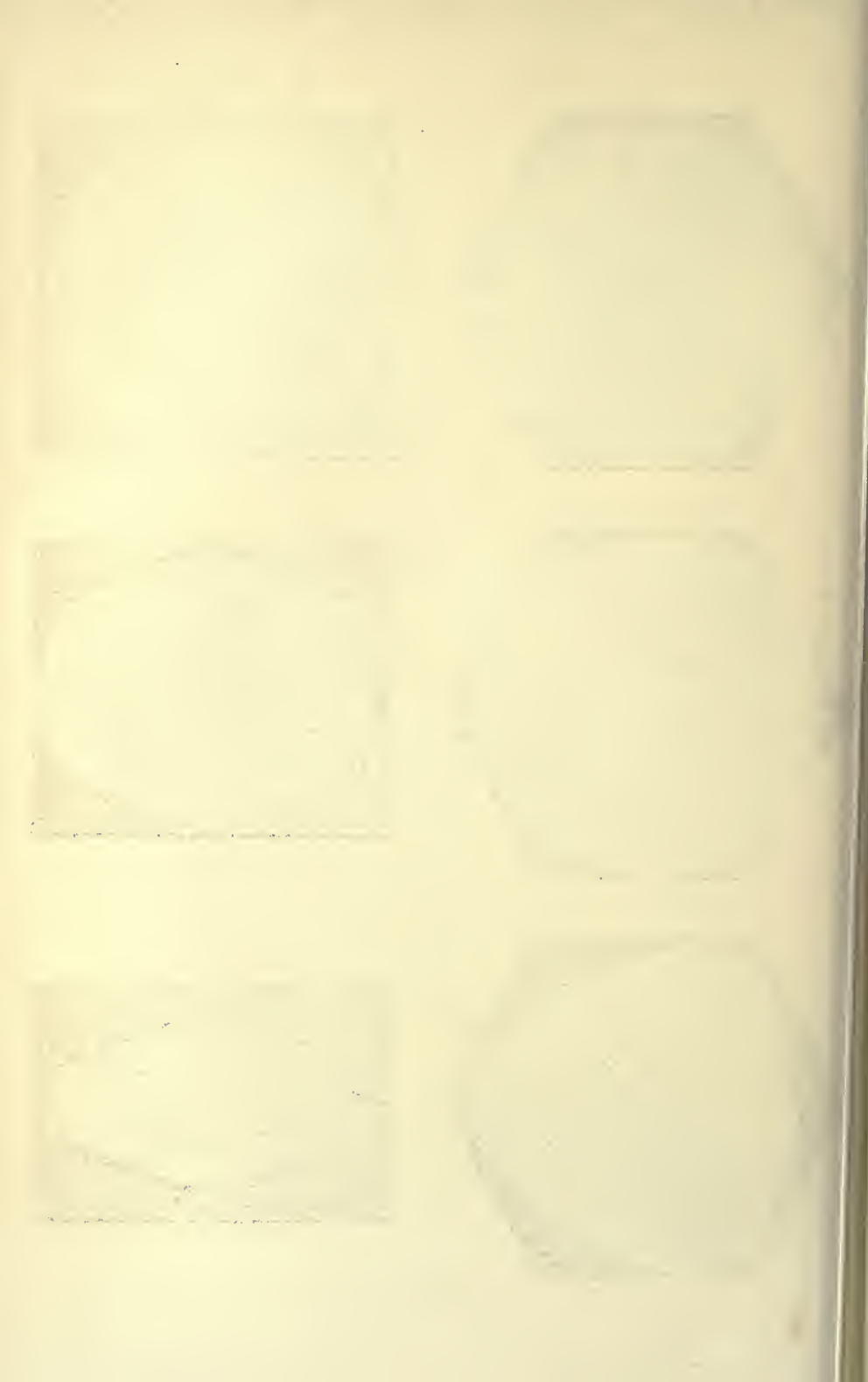


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quartz crystals in which he showed that hydrofluoric acid acts very unequally on the different kinds of faces, so that not only the right- and left-handed character of the crystals, but also all the complexity of twinning may be made to appear by etching. The experiments were repeated by us by placing simple quartz crystals from Herkimer, N. Y., in strong hydrofluoric acid and leaving them till sufficiently distinct etchings were produced. In these experiments, some of which were carried on in cold and some in hot acid, the character of the etching was in all cases the same, and as quartz is dissolved by the acid very slowly it is not probable that slight changes in the temperature or strength of the acid would have made any appreciable difference. On the ordinary quartz combination of prism, m ($10\bar{1}0$), positive rhombohedron r ($10\bar{1}1$), and negative rhombohedron z ($01\bar{1}1$), the following etchings are very easily developed: The positive rhombohedron r yields most readily to the action of the acid, becoming covered with elongated unsymmetrical depressions having a horizontal direction, the heaviest part being to the right in a right-handed crystal, figure 1, plate II, and to the left in a left-handed crystal, figure 2, plate II. The top and middle edges of these depressions are nearly straight, the bottom slightly curved, the widest end is terminated by a straight edge having the direction of the zonal edge between r and the adjacent z face. These etchings are distributed thickly over the r faces, and although they are not all exactly alike, their general character is well represented in figures 1 and 2. The effect of this action is also to eat away and replace all of the edges of the crystal toward which the heaviest ends of the etchings are turned; thus in a right-handed crystal between r and r ($10\bar{1}1$ and $1\bar{1}01$), r and z ($10\bar{1}1$ and $01\bar{1}1$) and r and m ($10\bar{1}1$ and $01\bar{1}0$) all to the right, while the corresponding edges to the left, toward which the points of the depressions on r are turned, are left perfectly sharp, except of course the upper parts where r ($10\bar{1}1$) forms a short edge with the adjacent r ($0\bar{1}11$) face to the left. In a left-handed crystal, this same phenomena can be observed only with the corre-

sponding edges eaten away to the left instead of to the right. This replacement of the edges is not shown in Figures 1 and 2, but is shown in the original figures of Leydolt, who also determined the symbols of the faces replacing the different edges. According to our experience the replacement of the edges appears more like an accumulation of little facets, all reflecting the light simultaneously, than a replacement made by a single face. For a discussion of the symbols of the faces and the determination of the twinning structure of quartz as shown by the etchings we refer our readers to the original paper of Leydolt. If the crystals are left in the acid for a sufficiently long time the edges between the rhombohedron faces become so far eaten away that nothing is left of the original rhombohedron faces and the prism is left terminated by the etching faces alone, which flatten out the crystal very much in the direction of the vertical axis.

On the negative rhombohedron z , the etchings are of an entirely different character, composed of a system of shallow depressions with curved contours, giving a sort of feather-like marking with the direction of greatest action turned toward the heaviest etching on the positive rhombohedron, Figures 1 and 2, plate II.*

The prismatic faces are much less acted upon than the rhombohedron faces, the etchings varying somewhat in character but consisting essentially of four-sided depressions with long and short vertical edges parallel to the edges of the prism, one straight steep edge on the side of the positive

* According to my experience, these etchings on the rhombohedron faces furnish one of the best methods of showing to a beginner in crystallography that the six faces which usually terminate a quartz crystal, are not the faces of an hexagonal pyramid, and all alike, but are those of positive and negative rhombohedrons. To prepare sections for showing this with a microscope, crystals should be etched till the markings are sufficiently distinct, then by cementing the crystal, with the etched face down, to a glass plate with Canada balsam and cementing glass plates on either side, the quartz can be ground away with emery till the glass plates form a large wearing surface and the quartz is ground to just the thickness of the glass plates; then after removing the slice of quartz and cleaning it, it can be cemented to an object-glass with the etched surface up and is ready for examination with the microscope. — PENFIELD.

rhombohedron *r* and parallel to the zonal edge between *m* and *z*, and a shorter slightly curved edge on the side of the negative rhombohedron *z*. These etchings have definite relations to the symmetry of the crystals and are of reverse character on right- and left-handed crystals, Figures 1 and 2, plate II. On adjacent prismatic faces, the longer or shorter vertical edges are turned toward each other, and by prolonged etching the alternating prismatic edges, toward which the shorter vertical edges of the etchings are directed, are slightly eaten away, while the other prismatic edges remain sharp and perfect.

From a consideration of the above we can now more readily understand the action of hydrofluoric acid on a sphere cut from a simple quartz crystal. A sphere of about 2.44 cm. diameter was purchased in New York, and etched by placing it in a lead crucible containing rather strong commercial hydrofluoric acid, such as can be bought in rubber bottles from dealers in chemicals. The exact strength of the acid was not determined. No special care was taken to place the sphere in any particular position in the acid, its position being accidentally changed nearly every day when the acid was removed. The solution of the quartz going on slowly, it may be assumed that the acid had a chance to act equally on all similar parts of the sphere. During the progress of the etching, which was carried on slowly in the cold, photographs of the etched sphere were obtained at three stages, which seemed well suited for illustration.

After leaving the sphere in the acid for a few hours, the etchings were distinctly observed and their arrangement on the sphere was such that its crystalline nature and relation to hexagonal axes could be determined. The location of the extremities of the vertical axis was marked by the centers of two triangular patches on opposite sides of the sphere, while the character and arrangement of the prominent etchings on the positive rhombohedron indicated the left-handed character of the crystal from which the sphere was cut, as well as the location of the extremities of the lateral axes. After

being in the acid for about four days some of the etchings were very prominent, and the sphere had the appearance represented in Figures 1 and 2, Plate III. In Figure 1 we are looking down upon the sphere in the direction of the vertical axis. In the centre there is a distinct, somewhat hexagonal field, the center of which marks the extremity of the vertical axis. This whole portion is one where the etching has gone on very vigorously, and with the microscope it may be seen that the surface is composed of minute triangular pyramids grouped closely together. About this, three prominent parts, which are arranged in the alternating sections of the hexagon, indicate the position of the positive rhombohedron by the greater extent of the etching, leaving very distinct prominences with their steep sides turned to the right. A distinct ridge or marking, from which the lines of etching go off very distinctly, can also be seen about in the center of each negative rhombohedron. In Figure 2, we are looking at the sphere about at right angles to a prismatic face. A little above the center of the figure and trending to the right, the prominent etchings, indicating the position of the positive rhombohedron, can be seen, while below and to the right they can also be seen in the position of the lower positive rhombohedron. On what may be called the equator of the sphere, midway between the above mentioned prominent etchings on the positive rhombohedrons above and below, the extremity of one of the lateral axes may be located a little to the right of the center of the figure. On much of the surface near the equator of the sphere, the original polish has not been destroyed. The vigorous action of the acid at the extremities of the vertical axis is plainly seen accompanied already by a slight flattening of the sphere.

After exposing the sphere again to the action of the acid for about two weeks it had the appearance represented in Figures 3 and 4, Plate III. In Figure 3, where we are looking down upon the sphere in the direction of the vertical axis, three parts on the equator, located by the right-hand and upper and lower left-hand angles of the hexagon, indicate one ex-

tremity of each of the three lateral axes, and from these parts the lines of etching run out very beautifully toward the center and the prominent marking on the rhombohedron faces. In Figure 4, where we are looking at right angles to the vertical axis, besides the decided flattening, a rhombic portion, about in the center of the field, is conspicuous, the center of which locates the extremity of one of the lateral axes. On this portion not only could the original curved surface of the sphere be detected but also the original polish. The acid having had apparently no action on this portion of the sphere, while the etched portions come up to meet this with sharp and distinct angles. Owing to a slight misunderstanding, a mistake was made in photographing Figure 4, which was not discovered till it was too late to correct it. If we imagine the sphere turned 90° so that the unattacked portion would appear at the right and seen at a tangent, while one of the two similar portions which are now behind and out of sight would appear in the front and a little to the left, the quartz would appear in just the right position to compare with Figures 2 and 6. As it is, we are looking at the crystal not at right angles to a prism m but at right angles to a prism of the second order (1210).

By exposing the quartz for about one month longer to the action of the acid it appeared as represented in Figures 5 and 6, Plate III. In Figure 5, which is again a vertical view, we can readily locate the extremities of the three lateral axes by the right-hand and upper and lower left-hand angles of the hexagon. At these parts the curved contour of the sphere is preserved for a short distance, but between them there is a decided tendency toward a triangular cross section. The sphere, as will be seen from Figure 6, has become extremely flattened, and the upper and lower portions meet along a sharply defined line. The etchings seem to arrange themselves along parallel lines or ridges, and some idea of their beautiful arrangement can be obtained from the larger reproduction shown in Figure 3, Plate II. In Figure 6 we notice, in addition to the extreme flattening, two of the three

portions where the acid has had very little action, one taken at a tangent to the right, the other a little to the left of the center; these appear as very conspicuous parallelograms; they have a curved surface similar to that of the original sphere, and although the original polish has disappeared from them only the finest etchings can be detected with the microscope. It can almost be said that the acid has had no action on these three surfaces, at least not enough to destroy the original polish of the sphere till toward the very end of the experiment, and not enough to appreciably diminish the diameter of the sphere. Although the original diameter was not accurately measured, care was taken, soon after commencing the etching, to cut a hole in a cardboard just large enough to allow the sphere to pass, and at the conclusion of the etching the quartz just touched at these three points when passed through the same hole.

The quartz was still further exposed to the action of the acid for about a week, but the general effect was not different from that shown in Figures 5 and 6. Of course the sphere was further flattened in the direction of the vertical axis and the three parts at the extremities of the lateral axes, where the acid had acted least, became considerably changed, being flattened out more in a vertical direction, and therefore appearing as parallelograms, relatively much more elongated horizontally. Figure 3, Plate II, is from a photograph taken at this stage, in which the relation of these parts to the longer sharp edge between them is less than in Figure 5, Plate III. At this stage the etching of the sphere was stopped and the specimen deposited in the collection of Prof. George J. Brush, New Haven, Conn.

In review it will be noticed, as is the case in all etching, that the acid acts very unequally on different faces of a crystal and therefore on different parts of the sphere; equally, however, on those similar parts of the sphere which are similarly situated with reference to hexagonal axes. The action is greatest at the two extremities of the vertical axis. The action seems to be to lift off or dissolve away layers of molecules from above and

below while there are three parts, each corresponding to one of the ends of the three lateral axes, where the acid exerts practically no solvent action. These parts diminish in size as the action of the acid continues, but not by any action of the acid upon them directly, except as the molecules were taken away from above, below, and at the sides. This is one of the most striking features of the experiment that in these three directions quartz is almost absolutely insoluble in hydrofluoric acid. As a study in symmetry, the experiment all along was a very interesting one. The etched sphere could never be divided by a plane into symmetrical halves and showed throughout all of the experiment the trapezohedral character of a quartz crystal. The sphere was cut from a crystal which would have shown etchings like those in Figure 2, Plate II. The accompanying illustrations give only a faint idea of the beauty of the etched sphere, it being impossible to reproduce the delicacy and beauty of the markings as they appeared on the perfectly transparent material of the quartz.

NOTE. — Owing to a mistake in interpreting the character of the etching figures, it was stated in the original article that the sphere was cut from a right-handed crystal. This error was pointed out by A. C. Gill (*Zeit. Kryst.*, vol. 22, p. 97). The forms shown by Figure 3, Plate II, and Figures 1-6, Plate III, are the result of etching a sphere cut from a *left-handed* quartz crystal.—EDITOR.

ON SPANGOLITE, A NEW COPPER MINERAL.

By S. L. PENFIELD.

(From Amer. Jour. Sci., 1890, vol. 39, pp. 370-378.)

DURING the summer of 1889, while visiting Mr. Norman Spang of Etna, Allegheny County, Pa., my attention was called by him to a beautifully crystallized specimen of an unknown mineral which he had obtained from a man living near Tombstone, Arizona. The original owner had a small collection of minerals which he had gathered together within a radius of about two hundred miles, but he had no idea of just where he had found the specimen, though he thought it was from the Globe District. Mr. Spang had forgotten the name of the man from whom he had secured it, so that until other specimens are found uncertainty must exist concerning the exact locality and mode of occurrence. On expressing a desire to investigate the mineral, Mr. Spang very generously lent me the specimen and has since presented me with it. It is now deposited in the collection of Professor Brush, at New Haven.

A preliminary blowpipe examination showed that the mineral was undoubtedly a new species and essentially a hydrated sulphate and chloride of copper, and I take pleasure in not only expressing at this time my thanks to Mr. Spang for his kindness but also in naming the mineral, which, as will be shown, is of unusual interest, *Spangolite*, after him.

The original specimen, which was about the size of a small hen's egg, consisted of a rounded mass of impure limonite which was mostly covered with hexagonal crystals of spangolite, associated with a few crystals of azurite and some slender prismatic crystals of a copper mineral containing chlorine, probably atacamite.

The crystallization of spangolite is hexagonal, rhombohedral. The habit of the crystals does not vary much as they all show a prominent hexagonal basal plane and a series of apparently holohedral hexagonal pyramids, which, as will be shown, must be taken as pyramids of the second order. Some of the crystals have the habit of Figure 1, showing a prism, which is always so dull and striated that it gives no reflection of light, associated with pyramids and a basal plane. Others are flatter, Figure 2, and show a large series of pyramids

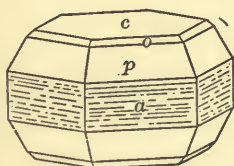


FIGURE 1.

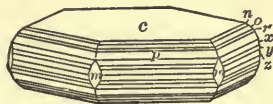


FIGURE 2.

which oscillate with one another, giving rise to prominent striations which run horizontally about the crystal and make the identification of the pyramids a difficult matter. On the crystals there is occasionally found a prism of the first order, *m*, which is small but gives good reflections. The material which could be used for the investigation was limited, but great care was taken to select only the best and purest crystals for making the crystallographic and chemical investigation. A number of small crystals were selected which were measured in the prominent pyramidal zones between the basal planes. The basal planes usually gave very good reflections of the signal but on turning the crystal on the goniometer, after the pyramids came into a position to reflect light, there usually followed an unbroken band of signals reflected from these faces, owing to their striations and oscillatory combinations. In this band of reflections prominent parts could usually be located which indicated the position of distinct pyramidal faces. On measuring fifteen independent pyramidal zones on five different crystals, only one crystal was found which gave sharp reflections from the

pyramidal faces; from this an angle was obtained of $c \wedge p$, $0001 \wedge 2\bar{1}12 = 63^\circ 32'$. Still better results were obtained on measuring from pyramid to pyramid, when the reflections of the signal are not so much disturbed by the striations and the value given below, which will be accepted as the fundamental measurement, was obtained

$$p \wedge p', 2\bar{1}12 \wedge 11\bar{2}2 = 53^\circ 11' 30''$$

From this the length of the vertical axis, $c = 2.0108$, was calculated.

The largest of all the crystals was fortunately so situated that it could be measured without detaching it from the specimen. It was very symmetrical and had the habit shown in Figure 1; it measured about 8 mm. in diameter and was $5\frac{1}{2}$ mm. high. The forms observed on this and other crystals are as follows:

c , 0001	k , 11 $\bar{2}$ 8	r , 33 $\bar{5}$ 8	x , 33 $\bar{6}$ 4
a , 11 $\bar{2}$ 0	n , 11 $\bar{2}$ 6	l , 33 $\bar{6}$ 7	y , 11 $\bar{2}$ 1
m , 1010	o , 11 $\bar{2}$ 4	p , 11 $\bar{2}$ 2	z , 33 $\bar{6}$ 2

Of the foregoing forms a , c , and p are prominent on all crystals, and o and m subordinate. The tables of measured and calculated angles, and the discussion of the forms on the more complex, striated crystals, Figure 2, are here omitted.

Cleavage. — The cleavage of spangolite is very perfect parallel to the base; this was a great help in studying the crystals as many of the measurements were obtained from cleavage planes. Inclined to the base the crystals usually broke with a conchoidal fracture; in only one case a distinct cleavage was observed parallel to the pyramid p , the angle of the cleavage measured on to the base being $63^\circ 28'$, calculated $63^\circ 33\frac{1}{2}'$. Thin plates of the mineral are non-elastic and brittle.

Etching. — Experiments made by etching the mineral with acids gave results which add very much to a proper understanding of the crystals. It is readily soluble in dilute mineral

acids and the perfect basal cleavage makes it easy to obtain oriented sections suitable for etching. The figures differed both with the character and strength of the acid, but always showed a decided rhombohedral symmetry. Figure 3 represents the character of some etchings produced by dilute sulphuric acid. The figures which are very perfect are about 0.066 mm. in diameter and have the shape of a section across a scalenohedron. Some of the depressions are bounded below by a basal plane, others taper to a point, while the scalenohedrons oscillate and give rise to delicate striations which are beautifully brought out under the microscope by a slight change of focus. The obtuse angle of the scalenohedron section measured under the microscope was about 133° , from which the relation on the lateral axes $a : \frac{5}{3}a : \frac{5}{2}a$, is calculated.

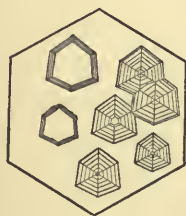


FIGURE 3.

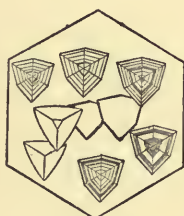


FIGURE 4.

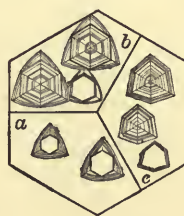


FIGURE 5.

This requires an angle of $133^\circ 10'$. Figure 4 represents some etchings produced by very dilute sulphuric acid: 1 c. c. of concentrated H_2SO_4 diluted with 80 c. c. of water. These also have a scalenohedral cross section and are about 0.06 mm. in diameter. The obtuse angle of the cross sections measures about 152° , from which its relation on the lateral axes $a : \frac{4}{3}a : 4a$ was calculated. The required angle is $152^\circ 12'$. There are also some steep rhombohedral depressions, with somewhat curved contours developed on this section. Some of the etchings produced by hydrochloric acid are shown in Figure 5, where the hexagon is divided into three parts. The figures shown in part *a* represent deep hexagonal depressions whose cross section is that of a pyramid of the second order; these have

a diameter of about 0.035 mm. and are surrounded above with shallow and very delicate rhombohedral depressions with curved contours. In part *b* we have again scalenohedral, surrounded by shallow and more delicate rhombohedral, depressions. The obtuse angle of the scalenohedral sections measured 129° , from which its relation on the lateral axes $a : \frac{7}{4}a : \frac{7}{3}a$ may be calculated. The required angle is $129^\circ 26'$. In part *c* we have again represented simple scalenohedron depressions which are about 0.025 mm. in diameter and were produced by a very dilute acid, 1 c. c. concentrated HCl diluted with 160 c. c. of water. The obtuse angle of the scalenohedron measured about 142° , indicating a relation on the lateral axes of $a : \frac{3}{2}a : 3a$. The required angle is $141^\circ 48'$. With nitric acid the figures are very similar to those produced by hydrochloric: in all cases it was observed that with very dilute acids there was a tendency to form scalenohedral, and with stronger rhombohedral, depressions. When we compare the position of these rhombohedral and scalenohedral etchings to the outer hexagon, which in Figures 3, 4, and 5 indicates the outline of the crystal section, we see at once that the pyramids on the mineral must be of the second order. It should be stated here that the etchings were of very great beauty and perfection, the outline of the scalenohedral cross sections being in almost all cases very distinct and free from distortions of any kind, so that the angles could be measured with comparative accuracy.

Optical properties. — The color of the mineral by reflected light is dark green, cleavage plates by transmitted light are light green. Prof. H. L. Wells examined a basal section of the mineral 0.4 mm. thick with the spectroscope. When the slit was very narrow the light transmitted by the mineral gave a narrow spectrum with a maximum of light in the green at about λ 525. There was a total absorption of the red and yellow, running well into the yellowish-green. At the other end of the spectrum there was a decided absorption of the blue and a total absorption of the violet. Pleochroism is not very marked. The ordinary ray is green while the extra-

ordinary is a decided bluish green. Cleavage plates show perfectly normal optical properties. In convergent polarized light they yield a black cross surrounded by rings which are bordered by green and blue. The double refraction is quite strong and negative. Considerable difficulty was obtained in making a prism from a crystal of the mineral with its edge at right angles to the perfect basal cleavage, but a small one was obtained, with an angle of $37^{\circ} 48'$, from which the indices of refraction were determined. The prism was opaque to the red and yellow lights of lithia and soda flames, even to the yellowish-green light of a thallium flame. With an ordinary kerosene flame the prism yielded two narrow green spectra, with a minimum deviation of $26^{\circ} 25'$ for the extraordinary and $28^{\circ} 46'$ for the ordinary ray. These were measured from the brightest part of the spectra, which, from the spectroscopic examination, had been located at about $\lambda 525$. The two indices of refraction from the values given above are $\omega 1.694$, $\epsilon 1.641$.

Other physical properties. — The hardness of the mineral on the basal plane is about 2, on the pyramidal faces nearly 3. The specific gravity was taken very carefully with a chemical balance on the purest material, which was selected for chemical examination. After boiling the crystals in water, to expel any air, three separate portions weighing respectively 0.2143, 0.1787, and 0.1538 grams gave 3.147, 3.133, and 3.142, an average of 3.141 as the specific gravity.

Chemical composition. — More than three grams of exceptionally pure material were readily obtained by sacrificing about one-half of the crystals on the specimen. As the material was somewhat limited, a method of analysis was adopted by which nothing could well escape detection and a qualitative and quantitative analysis was carried on with a single sample, the results of which are given below. The fourth analysis was made on an entirely different sample from that which yielded the figures in the first three columns.

The analysis yields a ratio of $\text{SO}_3 : \text{Cl} : \text{Al}_2\text{O}_3 : \text{CuO} : \text{H}_2\text{O} = 1.01 : 0.93 : 0.51 : 6.0 : 9.07$ or very nearly $1 : 1 : 0.5 :$

	I.	II.	III.	IV.	Average.	Ratio.		Calculated for $\text{Cu}_6\text{AlClSO}_{10} \cdot 9\text{H}_2\text{O}$
SO_3	...	10.08	10.11	10.14	10.11	0.126	1.01	10.03
Cl	4.12	...	4.10	4.11	4.11	0.116	0.93	4.45
Al_2O_3	6.59	...	6.51	6.70	6.60	0.064	0.51	6.45
CuO	59.57	...	59.47	59.50	59.51	0.7495	6.00	59.75
H_2O	...	20.32	...	20.49	20.41	1.134	9.07	20.32
					100.74			101.00
					O, equivalent of Cl	0.92		1.00
					99.82			100.00

6 : 9, from which the somewhat complicated and remarkable formula, $\text{Cu}_6\text{AlClSO}_{10} \cdot 9\text{H}_2\text{O}$ is obtained. No doubt can however exist concerning this formula; not only was the material beautifully crystallized and of unusual purity, but the analyses of two separate samples are identical within the error of analysis and the ratio is throughout very sharp; moreover the calculated composition agrees very well with the results of analysis. A slight deficiency in chlorine may result from a partial replacement of that element by hydroxyl, which, if true, would diminish somewhat the slight excess of water. The method of analysis was as follows: A weighed quantity of the mineral lost water slowly by standing in a desiccator over sulphuric acid, amounting to 0.30 per cent in thirty-six hours, but it regained almost all of this loss by standing uncovered in the air. Heated for an hour at 100°C . it lost about 0.49 per cent, but also regained this by standing in the air. The analyses were all made on air-dry powder. Water was determined by heating the mineral, contained in a platinum boat, in a hard glass tube provided with a loose plug of sodium carbonate at one end, through which the water vapors were conducted before absorption in a weighed chloride of calcium tube. A good deal of chloride of copper distilled off from the mineral. In some cases the contents of the boat were dissolved in nitric acid, the tube cleaned out carefully, and a complete analysis made on one portion. A new portion being taken, it was dissolved in nitric acid and the chlorine precipitated with silver nitrate. The weighed silver chloride when tested was found to contain no bromine

or iodine and when ignited in hydrogen gas yielded a weight of metallic silver agreeing with the composition AgCl . After removing the excess of the silver from the solution with hydrochloric acid the SO_3 was precipitated with BaCl_2 , care being taken to avoid a loss owing to the solubility of BaSO_4 in the aqua regia which was present in the analysis. After separating the excess of barium with sulphuric acid the solution was evaporated to expel the nitric acid, after which the copper was precipitated with hydrogen sulphide and weighed, after ignition in hydrogen gas, as Cu_2S . A portion of the copper precipitate was carefully tested for other metals, but none were found. The filtrate from the copper sulphide, when evaporated to dryness and ignited, left a residue which proved to be sulphate of alumina; this was dissolved in acid, precipitated in ammonia and weighed as Al_2O_3 . A weighed quantity of the oxide was carefully tested for beryllium, but none was found, and after conversion into sulphate and evaporation with the right quantity of K_2SO_4 it yielded alum crystals. The filtrate from the alumina yielded no perceptible residue when evaporated to dryness, proving that everything had been separated from the solution.

Pyrognostic and chemical tests. — Before the blowpipe the mineral fuses at about 3 to a black slaggy mass, coloring the flame green. On charcoal with soda in reducing flame it yields globules of metallic copper. Heated in the closed tube it gives abundant water which has a strong acid reaction. Insoluble in water, but readily soluble in dilute acids.

NOTE. — Since the publication of the foregoing paper spangolite has been identified by Professor H. A. Miers on two specimens from Cornwall. (*Min. Mag.*, vol. 10, p. 273.) The crystals from Cornwall are hemimorphic and, attention having been called to this fact, it may be seen that the crystals on the Arizona specimen are likewise hemimorphic. Figure 1, which shows no hemimorphic development, is in reality a twin. The nature of the twinning and the pyroelectric properties of the crystals are yet to be studied. — EDITOR.

ON MORDENITE.

By LOUIS V. PIRSSON.

(From Amer. Jour. Sci., 1890, vol. 40, pp. 232-237.)

UNDER the name of mordenite in 1864, How* published a description of a new zeolite, occurring at Morden and Peter's Point, Nova Scotia. To this species he assigned the general formula $RO \cdot R_2O_3 \cdot 9SiO_2 \cdot 6H_2O$. The correctness of this formula has long been considered doubtful, owing to the high ratio of silica to the bases and it is supposed that How analyzed a mixture of some zeolite with silica, more especially as his mineral did not occur in distinct crystals. It will therefore be of interest to announce the rediscovery of this interesting species in a new locality, to present a new analysis of pure material, proving the correctness of How's work, together with a discussion of its composition and a description of its crystal form and other physical properties.

The material upon which the present work is based I collected in October, 1889, while engaged in temporary field work on the Yellowstone Park division of the U. S. Geological Survey, in western Wyoming. The locality was one of the high points of the ridge running eastwardly from Hoodoo Mountain, and forming part of the divide between branches of Crandall Creek whose waters run into Clark's Fork and the head of the Lamar River or east fork of the Yellowstone. The locality is several miles from Hoodoo Mountain. The mordenite occurs lining the amygdaloidal cavities of a mass of decomposed basalt, one of the former inclusions in the basic breccia forming the ridge. At the time it was unfortunately supposed to be one of the commonly occurring zeolites and

* Jour. of the Chemical Soc., II, ii, p. 100, 1864.

only a small specimen was secured. Recently, while examining some material obtained in that region, this specimen came to light and as some tests failed to classify it, a complete investigation was undertaken, with the results here presented. In order to obtain enough material for analysis nearly the whole of the specimen had to be sacrificed. As the mordenite occurs in very small crystals, one of average size measuring under the microscope 1 mm. in height and breadth by about 0.4 mm. in thickness, it would have been impossible to pick out sufficient pure material for analysis.

A preliminary specific gravity determination showed it to be about 2.14 and it was therefore determined to separate it by means of the Thoulet solution, it being so much lighter than the pyroxene and other minerals that might be expected in the basalt. The specimen was therefore crushed fine enough to pass through an eighty-mesh sieve, washed free from dust and twice separated by the Thoulet solution. In the last operation the mordenite floated on a solution of 2.179, and sank when the density was lowered to 2.119. Its specific gravity is therefore between these two determinations. The density of the Thoulet solution was taken with a Westphal balance.

The material thus obtained after washing and drying, proved, on examination under the microscope, to be of exceptional purity, consisting wholly of crystal fragments, showing characteristic outlines and cleavage, and with no adherent particles of any foreign substance. The greater part were perfectly transparent and colorless; occasional fragments showed a very pale brownish discoloration in spots, as if due to the infiltration and deposition of a minute amount of iron ore or organic matter into cleavage cracks. In no respect as to appearance or their action on polarized light did these latter differ from the colorless pieces.

A test was again made with the Thoulet solution to ascertain if any difference in specific gravity could be found between the two. Very careful testing failed to show any whatever. Both floated and sank at precisely the same densities and in

precisely the same proportion. Great confidence is therefore felt in the purity of the material operated upon. The perfect separation by the Thoulet solution was no doubt due to the heavy, crumbly nature of the basalt with which the mordenite was associated and its own brittleness and low specific gravity. By this means about one gram of the pure mineral was obtained. It was thoroughly washed and dried at about 70° F. It was then finely powdered and subjected to analysis. A preliminary test showed that the mineral was scarcely attacked by boiling hydrochloric acid. The material was therefore divided into two equal portions and in the first, which was brought into solution by a mixture of sulphuric and hydrofluoric acids, everything was determined except the silica. The second portion was subjected to a sodium carbonate fusion and everything determined save the alkalies.

The water was first determined in both portions by ignition. It was given off easily, and the weight became constant at a moderate red heat. Before determining the water in No. I, it was found that the powdered mineral lost about 3.6 per cent of water by one hour's exposure to a heat of 100° C. The process for determining magnesia and the alkalies was as follows. After separating in No. I, the alumina and ferric oxides by ammonia and the lime by ammonium oxalate, the filtrate was evaporated and ignited gently in a platinum dish until all ammonium salts were driven off. The residue was then dissolved in a little water, and a roughly estimated amount of previously purified barium hydroxide added. By this means all the sulphuric acid and magnesia present were thrown down and the alkalies obtained in the filtrate in a form suitable for conversion into chlorides and for determination, after the excess of barium hydroxide had been removed by ammonium carbonate. The trace of magnesia was then easily separated from the precipitate of barium sulphate by hydrochloric acid, filtered off and determined.

The analysis was at all points carried on both as a qualitative as well as a quantitative one. It yielded the following results:

	I.	II.	Mean.	Ratio.		
SiO ₂	...	66.40	66.40	1.106	1.106	9.00
Al ₂ O ₃	11.32	11.01	11.17	0.1084	0.112	0.91
Fe ₂ O ₃	0.62	0.52	0.57	0.0036		
CaO	1.89	1.98	1.94	0.0346	0.113	0.92
MgO	0.20	0.14	0.17	0.0042		
K ₂ O	3.58	...	3.58	0.0379		
Na ₂ O	2.27	...	2.27	0.0366		
H ₂ O	13.31	13.31	13.31	0.7394	0.7394	6.01
Total	...	...	99.41	...	...	...

From these ratios it will be seen that the mineral agrees closely with How's general formula $\text{RO} \cdot \text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2 \cdot 6\text{H}_2\text{O}$, and if the slight amount of magnesia is taken as replacing lime it is evident that the protoxide bases are $\text{CaO} : \text{Na}_2\text{O} : \text{K}_2\text{O} = 1 : 1 : 1$. The composition is then $(\frac{1}{3}\text{K}_2\text{O}, \frac{1}{3}\text{Na}_2\text{O}, \frac{1}{3}\text{CaO}) \cdot \text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2 \cdot 6\text{H}_2\text{O}$. In the type of mordenite analyzed by How there was only a slight trace of potash and his composition showed $(\frac{1}{3}\text{Na}_2\text{O}, \frac{2}{3}\text{CaO}) \cdot \text{Al}_2\text{O}_3 \cdot 9\text{SiO}_2 \cdot 6\text{H}_2\text{O}$ and in the present mineral one molecule of K_2O replaces one of CaO in How's type. The ratios show a slight deficiency of the bases. For the sake of comparison we give below the theoretical percentages calculated for this formula and also present How's analysis and theory.

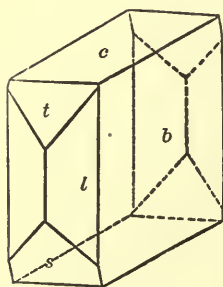
	Mean $\frac{1}{2}$.	Theory.	How $\frac{1}{2}$.	Theory.
SiO ₂	66.40	65.72	68.40	66.73
Al ₂ O ₃ (Fe ₂ O ₃)	11.74	12.53	12.77	12.74
CaO (MgO)	2.11	2.27	3.46	4.62
K ₂ O	3.58	3.82	...	...
Na ₂ O	2.27	2.52	2.35	2.56
H ₂ O	13.31	13.14	13.02	13.35
Totals	99.41	100.00	100.00	100.00

If, instead of accepting How's formula we take the ratio of the bases to the silica as found by my analysis, it will be seen that they give with remarkable exactness $\text{RO} : \text{Al}_2\text{O}_3 : \text{SiO}_2 : \text{H}_2\text{O}$ as $1 : 1 : 10 : 6\frac{2}{3}$. The formula becomes in this case $(\frac{1}{3}\text{K}_2\text{O}, \frac{1}{3}\text{Na}_2\text{O}, \frac{1}{3}\text{CaO}) \cdot \text{Al}_2\text{O}_3 \cdot 10\text{SiO}_2 \cdot 6\frac{2}{3}\text{H}_2\text{O}$. This

becomes in general $3\text{RAl}_2\text{Si}_{10}\text{O}_{24} + 20\text{H}_2\text{O}$, the three Rs being replaced by a molecule each of potash, soda, and lime.

In 1886, under the name of ptilolite, Cross and Eakins* described a new zeolite from Jefferson Co., Colorado, which, like the mordenite, occurs as a secondary formation in a basic lava. As the result of their investigations they assigned to the mineral the general formula $\text{RAl}_2\text{Si}_{10}\text{O}_{24} + 5\text{H}_2\text{O}$, in which R consisted of lime, potash and soda, not however in any simple ratio. The similarity of these two formulæ is very striking, and it seems evident that the two minerals belong to the same group of zeolites, the ratio of bases and silica being the same in each, the chief difference being that the ptilolite contains one-quarter less of water. In the crystal form and optical properties, however, the two zeolites are entirely unlike.

While this formula for mordenite confirms the work of Cross and Eakins in the existence of these very acid hydrous silicates, which can no longer remain doubtful, and the theoretical percentages calculated for it agree with very great closeness with the given analysis, it will be best, however, to retain the composition given by How on account of its greater simplicity and because it differs but slightly from the above.



In the symmetry of its crystal form mordenite is monoclinic and also isomorphous with heulandite. The crystal habit is shown in the figure and is remarkably similar to heulandite from Jones' Falls, near Baltimore, Md. The only forms observed were $c(001)$, $b(010)$, $l(450)$, $t(201)$ and $s(20\bar{1})$. The measurements were made on a Fuess goniometer, using the δ ocular of Websky. From the small size of the crystals and poor re-

flexions, owing to dulness of the faces and to striations due to a repetition of the crystal form in parallel position, a

* Amer. Jour. Sci., 1886, vol. 32, p. 117.

considerable series had to be examined before any sharp reflections could be obtained. No sharp reflections could be obtained from any clinopinacoid, since from the separation of cleavage plates it was invariably too rough to reflect well. Finally one crystal was found which gave very fair and distinct reflections in the prismatic zone and from the orthodomes. Another gave good reflections in the zone of symmetry. From these the following angles were taken as fundamental:

$$c \wedge t = 001 \wedge 201 = 63^{\circ} 40'$$

$$t \wedge s = 201 \wedge 20\bar{1} = 50^{\circ} 12'$$

$$s \wedge l = 20\bar{1} \wedge 450 = 36^{\circ} 07'$$

and from these we calculate the axial ratio

$$a : b : c = 0.40099 : 1 : 0.42792; \beta = 88^{\circ} 29'46''.$$

For heulandite we have,

$$a : b : c = 0.40347 : 1 : 0.42929; \beta = 88^{\circ} 34\frac{1}{2}',$$

adopting the orientation given the latter species by Des Cloizeaux. Only one other satisfactory measurement could be made:

	Calculated.	Measured.
$l \wedge l = 450 \wedge 4\bar{5}0$	$= 53^{\circ} 15'$	$52^{\circ} 44'$
		$52^{\circ} 33'$

The only difference then between the mordenite and the Jones' Falls crystals of heulandite is that the prism occurring on the latter if taken as (110) requires the similar prism on the mordenite to be (450).

The crystals occur attached at one end upon their prismatic faces. They form groups from growth parallel to the clinopinacoid, and are also somewhat radially disposed. The cleavage is eminently clinodiagonal and the luster of the clinopinacoid is pearly, so that cleavage fragments resemble small nacreous fish scales. Under the polarizing microscope, using cleavage plates of the mineral which furnish sections parallel to the clinopinacoid, it was found that the plane of

the optic axes is normal to this face. The direction of extinction is negative, according to the scheme adopted for the plagioclase feldspars and inclined about 15° to the clinodiagonal axis. This axis of elasticity = ϵ and $b = a$. The optic angle is large and it is uncertain whether ϵ or a is the acute bisectrix; the double refraction is weak, high polarization colors being shown only by the thickest sections between crossed nicols, while thin sections show gray of the first order. The hardness of mordenite is about 3. How gives 5 for his mineral. While it is difficult to ascertain the exact hardness of a species occurring in such small brittle crystals it was certainly not so hard as 5, and 3 is believed to be more correct. Before the blowpipe mordenite does not exfoliate; it gives off its water readily, practically without changing its form, and melts with some difficulty to a white enamel.

ON THE COMPOSITION OF POLLUCITE AND ITS OCCURRENCE AT HEBRON, MAINE.

By H. & L. WELLS.

(From Amer. Jour. Sci., 1891, vol. 41, pp. 213-220.)

It is a matter of great satisfaction to announce the discovery of pollucite in a new locality. This very interesting mineral has heretofore been found only on the Island of Elba and even there in very small quantities, so that it may be called a mineralogical rarity. Its composition, in being the only known mineral in which cæsium is an essential constituent, adds greatly to its interest.

Before describing the American material, some account of the history of the mineral may be given. In 1846, Breithaupt described * two minerals from Elba, which he called Castor and Pollux from their great similarity in appearance. He distinguished them easily however by their difference in specific gravity. Castor is now considered to be identical with petalite, and it is a fact worthy of mention that the latter mineral is found at Peru, Maine, only a few miles from the new pollucite locality, a fact which points, perhaps, to a new association of "Castor and Pollux." Breithaupt's material was analyzed by Plattner,† but at that time cæsium had not been discovered, so that he naturally mistook it for potassium. His results were as follows :

	1.
	Plattner.
SiO ₂	46.200
Al ₂ O ₃	16.394
Fe ₂ O ₃	0.862
K ₂ O	16.506
Na ₂ O ‡	10.470
H ₂ O	2.321
	92.753

* Pogg. Ann., lxi, 439.

† Ibid., p. 446.

‡ With trace of Li₂O.

Plattner sought in vain for an explanation of his low results, and not having enough material to repeat his analysis, he published it as it was. The discrepancy remained unexplained until in 1864, eighteen years later, and after Plattner's death, Pisani* discovered cæsium in the mineral. Pisani states that, if Plattner's analysis be recalculated on the supposition that the cæsium was weighed as platinichloride while the soda was calculated in the usual way from the weight of the mixed chlorides, that the results would correspond closely to his own analysis. Brush afterwards published a recalculation† on this assumption, which is given below under 1a. Since Plattner used 0.5 gram of substance for his analysis, the footing still hardly does justice to his well-known skill as an analyst. I have therefore made a new recalculation, given under 1b, assuming that Plattner's platinichlorides contained enough potassium to make an exact summation. This assumption is warranted to a certain extent by the fact that all analyses of pollucite since Plattner's give at least a trace of potash. This calculation of the potash cannot be considered very exact, but it is quite probable that a part of the excess shown by the other recalculation was due to the presence of this substance.

1 a.			1 b.		
	Plattner, Recalculated.	Ratio.		Plattner. Recalculated.	Ratio.
Si ₂ O	46.20	0.770 or 4.64	SiO ₂	46.20	0.770 or 4.64
Al ₂ O ₃	16.39 0.161		Al ₂ O ₃	16.39 0.161	
Fe ₂ O ₃	0.86 0.005		Fe ₂ O ₃	0.86 0.005	
Cs ₂ O	35.69 0.127	0.155 or 0.93	Cs ₂ O	29.80 0.106	0.163 or 0.98
K ₂ O			K ₂ O	2.71 0.029	
Na ₂ O	1.72 0.028		Na ₂ O	1.72 0.028	
H ₂ O	2.32	0.129 or 0.78	H ₂ O	2.32	0.129 or 0.78
	103.18			100.00	

The analysis which Pisani made on his discovery of cæsium in the mineral, is as follows:

* C. R. lviii, 714.

† Amer. Jour. Sci., 1864, vol. 38, p. 115.

	2.		2a.
	Pisani.	Ratio.	Ratio with assumed correction (Na ₂ O = 2.17 per cent).
SiO ₂	44.03	0.734 or 4.56	0.734 or 4.56
Al ₂ O ₃	15.97	0.157	0.161 or 1.00
Fe ₂ O ₃	0.68	0.004	
CaO	0.68	0.012	
Cs ₂ O *	34.07	0.121	0.168 or 1.04
Na ₂ O *	3.88	0.063	
H ₂ O	2.40	0.133 or 0.83	0.133 or 0.83
	101.71		

Pisani is very positive about the freedom of his cæsia from any considerable amount of potash, and he determined the atomic weight of his alkali-metal in support of this; hence it is scarcely allowable to recalculate his analysis, as has been done in the case of Plattner's, with the assumption that the excess was due to the presence of potash. It is the author's opinion, from a consideration of one of Rammelsberg's analyses which will be mentioned later and of the analyses of the new material from Maine, that Pisani's excess was at least largely due to too much soda, either derived from glass vessels or from some other cause, hence a ratio is given under 2a above, after deducting 1.71 per cent of soda from the analysis. Pisani deduced from his analysis the oxygen ratio, SiO₂ : Al₂(Fe₂)O₃ : Cs₂(Ca₁Na₂)O : H₂O = 15 : 5 : 2 : 2. This ratio would be expressed by the very complicated formula, 45SiO₂ . 10Al₂O₃ . 12Cs₂O . 12H₂O.

Pisani certainly left the question of the true composition of pollucite open to doubt, and in 1878 Rammelsberg published † a new analysis of the mineral with the view of clearing up the doubt. Rammelsberg's material was evidently not well adapted to the purpose of determining the composition of the mineral, for he first picked from it some pieces, "more or less translucent," and obtained from them, Al₂O₃ 16.58, alkalis precipitated by platinic chloride 23.03, Na₂O 2.00, Li₂O 0.83; then he picked from the same material some fragments which

* With traces of K₂O and Li₂O.

† Berlin. Akad., 9, 1878.

had a specific gravity of 2.868, the lowest number which has ever been given for the mineral, although Breithaupt gives the same number as the lowest of a series, and he made the following analysis from it:

3.			
	Rammelsberg, First analysis.		Ratio.
SiO ₂	[48.15]		[0.802 or 5.01]
Al ₂ O ₃	16.31		0.160 or 1.00
Cs ₂ O	30.00	0.106	} 0.151 or 0.94
K ₂ O	0.47	0.005	
Na ₂ O	2.48	0.040	
H ₂ O	2.59		0.144 or 0.90
	100.00		

On this single analysis, where an important constituent was determined by difference and where the material was of questionable purity, Rammelsberg obtains the formula which is now generally accepted for the mineral. The analysis corresponds to the formula $H_2R'_2Al_2(SiO_3)_5$; Rammelsberg includes the hydrogen in R' and writes it $R'_4Al_2(SiO_3)_5$.

It may be inferred that Rammelsberg himself was not fully satisfied with his results, for about two years later, he published * an analysis of what he describes as the purest material. This analysis is given below.

4.				
	Rammelsberg, New analysis.			Ratio from the mean of 4.
	I.	II.	III.	
SiO ₂	46.48	...	...	0.775 or 4.58 or 9.16
Al ₂ O ₃	...	17.24	...	0.169 or 1.00 or 2.00
Cs ₂ O	...	30.71	30.53	0.109
K ₂ O	...	0.78	0.41	0.006
Na ₂ O	...	2.31	2.19	0.036
H ₂ O	2.32	...	...	0.129 or 0.76 or 1.52
				3.30

He does not publish any ratio with this analysis, but says: "*These results confirm the former.*" The emphasis is Rammelsberg's. It may be noticed, however, that this analysis

* Berlin. Akad., 671, 1880.

corresponds very closely to the formula, $9\text{SiO}_2 \cdot 2\text{Al}_2\text{O}_3 \cdot 2\text{R}'_2\text{O} \cdot 1\frac{1}{2}\text{H}_2\text{O}$, or putting in H with R', it corresponds very well with the metasilicate formula, $\text{R}'_6\text{Al}_4(\text{SiO}_3)_9$. Moreover the formulæ just mentioned correspond much better with the analyses of Plattner and Pisani than Rammelsberg's formula does. What the probable formula for pollucite is, will be discussed after giving the analysis of the Hebron mineral.

The locality, Hebron, from which the new material comes, furnished the lepidolite from which Allen* extracted a large quantity of cæsium and rubidium, the material used by Johnson and Allen† in determining the atomic weight of cæsium as now accepted. Hebron also furnished the remarkable beryl in which Penfield‡ found 2.92 per cent of cæsium oxide. It might have been expected, therefore, that this locality would be likely to furnish pollucite; indeed, Professor Brush tells me that he has tested a large quantity of quartz fragments from the locality, hoping that some of them might be this mineral.

The specimens were found during the past summer by Mr. Loren B. Merrill, of Paris, Me., and a few pieces were sent by him for identification to Professor Brush, who very kindly gave them to the author for examination. Mr. Merrill has since very generously loaned us his whole stock of the mineral, amounting to more than half a kilogram, in order that a thorough examination might be made. The mineral is said by the discoverer to have been found in only two cavities. In one of these only two or three pieces were found, associated with large, etched quartz crystals. In the other cavity the main part of the mineral was found in a loose heap mixed with clay. This last cavity was open at the top, and was three feet wide, six feet long, and eighteen inches deep. It was associated with quartz, a crystal of which was in one case imbedded in the pollucite, also with psilomelane and with another mineral which proves to be a nearly colorless, brilliant cæsium-beryl. The pollucite was in the form of irregular

* Amer. Jour. Sci., 1862, vol. 34, p. 367.

† Ibid., 1863, vol. 35, p. 94.

‡ Ibid., 1884, vol. 28, p. 29.

fragments, mostly between $\frac{1}{4}$ and 10 grams in weight, very similar to those figured by Breithaupt in his original description of the mineral from Elba. The substance of many of the fragments, such as were used for the analysis, was of the most perfect physical character, perfectly colorless and as brilliant and transparent as the finest glass.

Professor S. L. Penfield has kindly made the following report of an optical examination of the substance:

“Refractive indices on a prism of $43^{\circ} 41'$:

$$n = 1.5215 \text{ Li}$$

$$n = 1.5247 \text{ Na}$$

$$n = 1.5273 \text{ Tl}$$

“The mineral shows no double refraction, hence it is isometric. Under the microscope it is very free from inclusions. Some of the specimens show a series of holes, in parallel position, extending into the substance of the fragment at right angles to its surface. These holes have rectangular cross-sections and they give to some of the specimens a sort of fibrous structure.” Unfortunately, none of the fragments have any distinct crystalline faces.

In its pyrognostic properties, its luster and hardness, and its lack of any apparent cleavage, it agrees exactly with the observations of Breithaupt, Plattner, and the other observers in regard to the Elba mineral. It is completely, though slowly, decomposed by hydrochloric acid with the separation of pulverulent silica. This agrees with the observations of Plattner and Pisani, but not with the statements of Rammeisberg. The latter was doubtless deceived by the slowness of the action, for it takes several hours to decompose the finely pulverized mineral with moderately concentrated acid at the heat of the water-bath.

The specific gravity of the Hebron mineral was taken twice on each of two fragments; one gave 2.985 and 2.987, the other 2.976 and 2.977. It will be noticed that the Maine mineral is considerably heavier than that from Elba. Breithaupt gives 2.868, 2.876, 2.880 and 2.892; Pisani gives

2.901; Rammelsberg gives for the material used in his first analysis 2.868, and for the pure material used in his second, 2.885 to 2.896. All of this European material, except that used by Rammelsberg for his first analysis, is described by the various observers as being colorless and transparent. The indications are that the higher specific gravities represent the better material, and the comparatively high specific gravity of the American mineral seems to point to still better quality if not to some difference in composition.

A single piece of the very best quality was selected for the chemical examination, while the water was determined in two other fragments also, because of the evident importance of the water in calculating the formula. Analyses I and II were first made, but, as they did not show a perfect agreement in the determinations of the alkalies, No. III was then made with the greatest care. This last is considered the best of the analyses and the ratio given is calculated from it, but it will be noticed that the other two analyses confirm this quite well and that they both point to the same formula with almost equal sharpness.

Water was determined by loss by ignition, as given in detail beyond; the "intense ignitions" were made in small platinum crucibles over a powerful blast-lamp flame, so that the heat obtained was very high. The material was not dried in any way before weighing. The mineral was decomposed by hydrochloric acid, and silica, alumina, and lime were determined by the usual methods, care being taken to take account of the slight impurities in the silica and alumina. The alumina contained a very faint trace of iron, no more than might have been introduced by breaking the mineral up with steel cutters; no evidence could be found of the presence of other elements in the alumina. The identity of the lime was shown by the spectroscope.

The alkali-metals were weighed together as chlorides, then cæsium and potassium were separated and weighed as platinum-chlorides; the alkali-chlorides in the latter were separated and weighed in order to calculate the proportion of cæsia and

potash. The potassium spectrum was detected from these last chlorides with considerable difficulty, while they showed no rubidium spectrum whatever. Lithium chloride was separated from sodium chloride, after the removal of the excess of platinum, by the method of Gooch, and the soda was calculated from the difference between the other chlorides and the total mixed chlorides, while in analysis III the sodium chloride was also weighed directly, giving a result which happened to be exactly identical with the indirect determination. This agreement of the direct with the indirect determination of the soda may be considered as an indication that the other alkalis were determined with reasonable accuracy. The lithium was identified with the spectroscope.

The following are the results of the analyses:

	Single piece.			Two separate pieces.	
	I.	II.	III.	IV.	V.
Weight of substance taken . .	0.6260	1.1291	0.9491	1.0205	1.4826
Loss by heating at 125°-130°	...	...	0.00	...	...
Loss by heating at 165°-170°	...	...	...	0.03	0.01
Loss by heating to red heat .	1.49	...	1.50	1.56	1.50
Loss by intense ignition . . .	0.04	...	...	0.02	0.03
H ₂ O	1.53	[1.53]	1.50	1.58*	1.53*
SiO ₂	43.48	43.59	43.51		
Al ₂ O ₃	16.41	16.39	16.30		
CaO	0.21	0.22	0.22		
Cs ₂ O	36.77	35.36	36.10		
K ₂ O	0.47	0.51	0.48		
Na ₂ O	1.72	2.03	1.68		
Li ₂ O	0.03	0.04	0.05		
	100.62	99.67	99.84		

The ratio calculated from No. III, and the calculated composition, giving the alkalis the same proportion as in the analysis, but omitting lime and lithia as insignificant, is given beyond:

* Not including, respectively, 0.03 and 0.01 per cent of water lost at 165°-170°.

Hebron Pollucite. Ratio from analysis III.				Calculated for $H_2R'_4Al_4(SiO_3)_9$ ($R' = \frac{1}{168} Cs, \frac{1}{168} K, \frac{1}{168} Na$).
SiO ₂	0.725 or 4.53 or 9.06			SiO ₂ 43.55
Al ₂ O ₃	0.160	1.00	2.00	Al ₂ O ₃ 16.45
CaO 0.004	0.166	1.04	2.08	Cs ₂ O 36.38
Cs ₂ O 0.128				K ₂ O 0.48
K ₂ O 0.005				Na ₂ O 1.69
Na ₂ O 0.027				H ₂ O 1.45
Li ₂ O 0.002				
H ₂ O	0.083	0.52	1.04	100.00

The sharpness of the ratio and the agreement of the analysis with the calculated composition are all that could be desired. There can be no doubt, then, that the composition of the Hebron mineral is represented by the formula $9SiO_2 \cdot 2Al_2O_3 \cdot 2R'_2O \cdot H_2O$ or $H_2R'_4Al_4(SiO_3)_9$. The theoretical composition for $H_2Cs_4Al_4(SiO_3)_9$, supposing no alkalis except Cs₂O to be present, is,

SiO ₂	40.72
Al ₂ O ₃	15.39
Cs ₂ O	42.53
H ₂ O	1.36
	100.00

A comparison of all the ratios given in this article, as shown in the following table, makes it probable that the new formula can be assigned also to the Elba mineral. The ratios have been calculated with Al₂O₃ as unity because it shows less variation throughout the analyses than the other constituents.

Leaving out of consideration Rammelsberg's first analysis, there can be little doubt that the new formula expresses the composition of Elba pollucite as far as the first three members of the ratios are concerned, but the water is 0.8–0.9 per cent higher in the analyses of that material than the formula requires. A part of this excess may be accounted for by supposing it to take the place of any deficiency in the alkalis, as will be noticed especially in the last analysis of Ram-

	Ratios.			
	SiO ₂ :	Al ₂ O ₃ (Fe ₂ O ₃) :	R ₂ O :	H ₂ O.
Plattner's analysis as recalculated by Brush	4.64 :	1.00	: 0.93 :	0.78
Plattner's analysis newly recalculated	4.64 :	1.00	: 0.98 :	0.78
Pisani's analysis	4.56 :	1.00	: 1.22 :	0.83
Pisani's analysis with assumed correction . .	4.56 :	1.00	: 1.04 :	0.83
Rammelsberg's analysis on which he based his formula	[5.01]:	1.00	: 0.94 :	0.90
Rammelsberg's later analysis	4.58 :	1.00	: 0.89 :	0.76
Analysis of Hebron pollucite	4.53 :	1.00	: 1.04 :	0.52
Proposed formula requires	4.50 :	1.00	: 1.00 :	0.50
Rammelsberg's formula requires	5.00 :	1.00	: 1.00 :	1.00
Or, as he writes the latter	5.00 :	1.00	: 2.00	

melsberg; hence, since the small excess of water cannot be introduced into the formula without complicating it greatly and destroying the metasilicate ratio, it is probably best to consider it as accidental. The replacement of a small part of the alkalis by water in the Elba mineral would explain its lower specific gravity.

It is satisfactory to notice that the historical first analysis by Plattner confirms, in each of its recalculated forms, the conclusions arrived at in this paper.

THE CHEMICAL COMPOSITION OF IOLITE.

By O. C. FARRINGTON.

(From Amer. Jour. Sci., 1892, vol. 43, pp. 13-16.)

As is well known, the formula of iolite has never been satisfactorily established. This is chiefly for the reason that the state of oxidation of the iron, in the analyses hitherto published, has not been determined. Stromeyer,* Gmelin† and Schütz,‡ who made the earlier analyses, regarded the iron as protoxide. Scheerer,§ however, in 1846, in connection with analyses of iolite from Kragerö, urged that it was more probably present as sesquioxide, his reason being stated as follows :

“Das Verhältniss des Sauerstoffs der Kieselerde zu dem der Thonerde und zu dem der 1 und 1 atomigen Basen ergiebt sich hiernach wie: SiO_2 26.20 : Al_2O_3 15.26 : RO 5.48 wenn man nämlich annimmt, dass die geringe Menge Eisen als Oxydul im Mineral vorhanden sei. Diess dürfte aber schwerlich der Fall sein, da der analysirte Cordierit fast völlig farblos war und auch nicht den geringsten Stich ins Grünliche zeigte, während es bekannt ist, dass verhältnissmässig sehr kleine Quantitäten Eisenoxydul hinreichend sind, um einen (nicht pulverformigen) Silicate eine deutlich grüne Farbe zu ertheilen, sobald diess natürlich nicht durch andere färbende Substanzen verhindert wird. Nimmt man daher gewiss mit mehr Recht das Eisen in Zustande des Oxyds an, so wird das Sauerstoffverhältniss SiO_2 26.20 : R_2O_3 15.64 : RO 5.26.”

This conclusion of Scheerer has been accepted by most later writers. Rammelsberg,|| regarding the iron as sesquioxide,

* Unters., Rg. Min. Ch.

† Schweigger's J., xiv, 316.

‡ Pogg. Ann., liv, p. 565.

§ Pogg. Ann., lxxviii, p. 319.

|| Mineralchemie, 1875, p. 652.

deduces the generally accepted formula, $2\text{MgO} \cdot 2\text{R}_2\text{O}_3 \cdot 5\text{SiO}_2$, although the ratios are not very satisfactory. He also suggests $\text{Mg}_3\text{R}_6\text{Si}_5\text{O}_{23}$ as a possible formula. Water seems to have been disregarded.

At the locality in Guilford, Conn., recently described by Dr. E. O. Hovey,* iolite occurs as stated by him, as a constituent of the rock mass. This locality was visited by the writer, and it was also found that veins of more coarsely crystalline material running through the gneiss, contained the mineral in grains as large as a walnut and even in pieces of sufficient size for hand specimens. These large grains are very clear and transparent, and show none of the tendency to alteration so characteristic of the iolite from other localities.

The exceptional purity of this material led the writer to make a chemical analysis of it, and care was taken to use only those grains which were perfectly clear and showed the characteristic pleochroism of the mineral. A determination of the state of oxidation of the iron was included in the analysis, FeO being determined by decomposition of a separate portion with hydrofluoric and sulphuric acids and titration with potassium permanganate. Water was determined directly, by fusing about a gram of the mineral with dry sodium carbonate in a Gooch tubulated crucible and collecting in a chloride of calcium tube. The precaution was taken to surround the first crucible with another containing sodium carbonate, so that no products of combustion from the flame could penetrate the red-hot platinum and render the result too high. The analysis gave the following results:

	I.	II.	Mean.	Ratio.	
SiO_2	49.44	49.56	49.50	0.825	5.00
Al_2O_3	32.97	33.04	33.01	0.324	1.98
Fe_2O_3	0.35	0.41	0.38	0.002	
FeO	5.11	5.13	5.12	0.071	2.03
MnO	0.32	0.27	0.29	0.004	
MgO	10.39	10.46	10.42	0.260	
H_2O	1.65	1.58	1.62	0.090	0.54
	100.23	100.45	100.34		
Sp. Gr.	2.607				

* Amer. Jour. Sci., 1888, vol. 36, p. 57.

From this it will be seen that nearly all of the iron is present as protoxide. The analysis also shows the ratio of $\text{SiO}_2 : \text{R}_2\text{O}_3 : \text{RO} : \text{H}_2\text{O}$, to be very nearly 5 : 2 : 2 : 0.5.

In order to test these results by comparing different material, an analysis was also made of iolite from the well known locality at Haddam, Conn., the specimens being very kindly furnished by Professor Brush from his private collection.

This analysis resulted as follows :

	I.	II.	Mean.	Ratio.	
SiO_2	49.25	49.03	49.14	0.819	0.819
Al_2O_3	32.81	32.87	32.84	0.322	0.326
Fe_2O_3	0.58	0.67	0.63	0.004	
FeO	5.06	5.01	5.04	0.070	0.333
MnO	0.19	0.19	0.19	0.003	
MgO	10.51	10.30	10.40	0.260	0.102
H_2O	1.81	1.88	1.84	0.102	
	100.21	99.95	100.08		
Sp. Gr.	2.610				

Here the percentages of Fe_2O_3 and H_2O are slightly larger than in the other analysis, but this might almost be expected on account of the strong tendency of the Haddam mineral to alteration. The ratios, however, as will be seen, are almost exactly the same as those given by the Guilford mineral. The formula of iolite is therefore $\text{H}_2\text{O} \cdot 4(\text{Mg}, \text{Fe})\text{O} \cdot 4\text{Al}_2\text{O}_3 \cdot 10\text{SiO}_2$, the ratio of $\text{MgO} : \text{FeO}$ being in these two analyses very nearly 7 : 2. The theoretical percentages according to this formula are given below, and for comparison, the mean of each of the two analyses calculated to 100 per cent, the small quantities of Fe_2O_3 and MnO being reckoned as Al_2O_3 and MgO respectively.

	Theory.	Calc. to 100.	
		Guilford.	Haddam.
10SiO_2	49.40	49.41	49.21
$4\text{Al}_2\text{O}_3$	33.60	33.17	33.30
$\frac{2}{3}(4\text{FeO})$	5.27	5.40	5.24
$\frac{2}{5}(4\text{MgO})$	10.25	10.40	10.41
H_2O	1.48	1.62	1.84
	100.00	100.00	100.00

These results show satisfactory agreement, and the percentages, it may be said, do not differ materially from those of the hitherto published analyses except in the state of oxidation of the iron. The fact that the iron is present as FeO , in spite of the lack of green color, which caused Scheerer's conclusion to the contrary, shows how little reliance is to be placed on color. Indeed, in a recent description of colorless iolite from Brazil,* Dr. Groth expresses the belief that the usual violet color of the mineral must be merely due to a pigment and not to any essential constituent. For the purpose of determining the nature of the water, about a gram of the Guilford mineral was subjected to increasing temperatures until constant weights were obtained at each. The results were as follows:

	100° C.	300° C.	Faint redness.	Full redness.	Total.
Loss in weight	None	0.63	0.87	0.10	1.60

Up to full redness the mineral remained light in color but on further heating, over the blast lamp, it turned black, baked together and showed a slight increase in weight, owing doubtless to oxidation of the iron.

It will be seen that the percentage lost by heating to full redness is the same as that of water found by actual determination. Hence loss by ignition at this degree of temperature can safely be taken as representing the amount of water. In the Haddam iolite it was therefore determined in this way. It is possible that too low ignition may account for the small percentage of water (0.50 per cent) found by Jackson in one of his analyses. All other analyses thus far published show amounts of water between 1 and 2.5 per cent, the average from six analyses being 1.74 per cent.

The high temperature required to drive off the water shows that it is practically all constitutional. If present as hydroxyl, it is possible that it combines with Mg to form the univalent radical (MgOH). The recent investigations by

* Zeitschr. Kryst., vol. vii, p. 594.

Clarke and Schneider* seem to indicate that, if the above molecule is present in a silicate, it can be decomposed by the action of dry HCl gas, so that an equivalent of MgCl_2 can be dissolved out by water. An experiment, conducted to test this point, gave no satisfactory results. About a gram of the mineral was heated in a current of the dry gas for 8 hours and nearly constant weight was attained. On leaching, however, with water and a drop of nitric acid, only 0.14 per cent of MgO went into solution, so that no definite conclusion could be drawn from this result.

On digesting a sample with strong aqueous HCl for three days, on the water bath, the following results were obtained:

		Ratio to per cent in complete analysis.
Undecomposed mineral	23.20	
SiO_2	36.79	0.75
Al_2O_3 with Fe_2O_3	30.50	0.78
MgO with MnO	8.04	0.77
HO_2	1.84	
	<u>100.37</u>	

From the above it is seen that about 76 per cent of the mineral had dissolved and since the different constituents were about equally affected, it seemed probable that by longer treatment the mineral could be completely decomposed. Accordingly another sample was digested, on the water bath, for fifteen days. The result showed the supposition to be correct, since the insoluble residue was found to be 49.95 per cent or very nearly the percentage of SiO_2 in the mineral. The mineral therefore is completely decomposed by long treatment with hydrochloric acid.

In conclusion the author wishes to express his especial indebtedness to Professor S. L. Penfield, for much valuable assistance and advice rendered during the work.

* Amer. Jour. Sci., 1890, vol. 40, p. 303.

ON ARGYRODITE AND ITS OCCURRENCE AT A NEW LOCALITY IN BOLIVIA.

By S. L. PENFIELD.

(From Amer. Jour. Sci., 1893, vol. 47, pp. 107-113.)

NOTE. — The title of this article as originally published was as follows: "On Canfieldite a new Germanium Mineral and on the Chemical Composition of Argyrodite." As will be shown, the crystallization of the mineral from Bolivia is isometric, and that from the original locality in Freiberg, in Saxony, having been described as monoclinic it was supposed that the two minerals were dimorphous; hence the name Canfieldite was assigned to the isometric variety. It was afterwards shown that the Freiberg argyrodite is isometric and not monoclinic; hence the name Canfieldite was transferred to the isomorphous tin compound, subsequently discovered. See page 242. — EDITOR.

It is with great pleasure that the author is able to announce the discovery of a new mineral containing germanium and to record the occurrence of this rare and interesting element from a new locality. The credit of this is due in great measure to the keen mineralogical interest of Mr. Frederick A. Canfield, of Dover, N. J., to whom, while on a business trip in Bolivia, South America, some specimens of this mineral were given as samples of a rich and unknown silver ore, by friends connected with the mining industry. These were brought to the writer for identification and he takes great pleasure here in acknowledging his indebtedness to Mr. Canfield and in expressing his thanks to him for the liberality with which he has placed an abundant supply of this valuable material at his disposal. It is in acknowledgment of these services that the mineral has been named after him.

It is unfortunate that at the present no further information can be given concerning the exact locality and mode of

occurrence, but from inquiries that have been set on foot by Mr. Canfield it is hoped that full data concerning these points may be given later.

When the mineral was brought to the writer, attempts made to identify it at once showed that it was not one of the ordinary silver minerals. Thus in the open tube it gave a reaction for sulphur but no sublimate. In the closed tube with a Bunsen burner flame only a slight sublimate of sulphur, but at a higher temperature with a blowpipe flame the sulphur increased, while nearer the assay a pale yellow sublimate formed, which became lighter on cooling. On examining this with a lens it was found to consist of minute globules, most of which were nearly colorless but some were yellow. Boiling concentrated nitric acid was found to attack and oxidize the mineral very slowly. On charcoal in the oxidizing flame it fused readily and gave almost immediately a pure white sublimate near the assay, but no color to the flame. On continued blowing this sublimate moved farther out, assuming a color which varied from greenish to brownish yellow, for the most part lemon yellow, while the assay changed to a pure silver bead. On examining the coating more minutely with a lens it was seen to have a peculiar smooth appearance, as if it had fused on the surface of the charcoal, while scattered about nearer the assay were numerous small transparent to milk-white globules, along with minute globules of silver. These tests led to the suspicion that the mineral might possibly contain germanium, and a comparative test, made with argyrodite on charcoal, gave exactly the same results. It is to be noted here that while Richter* describes very minutely the reactions which argyrodite gives on charcoal he does not mention the smooth surface of the coating or the formation of the fused globules which form so characteristic and useful a test for the identification of germanium. In order to prove beyond all doubt the identity of the element thus indicated with germanium the properties of the element

* Quoted by Weisbach, *Jahrb. f. Min.*, 1886, ii, p. 67.

as given by Winkler* were studied and a series of careful qualitative tests were made together with the formation of most of the important compounds mentioned by him. Thus a sulpho-salt, soluble in alkaline solutions like those of the tin, arsenic, and antimony group, was prepared, from which solution the addition of acid, especially in large excess, precipitated a white sulphide. On heating some of this sulphide in a tube through which a current of hydrogen was passed, small glittering scales of GeS , in luster resembling hematite, were formed just beyond the ignited material. These on examination with the microscope in transmitted light were found to be dark brown in color. Although not mentioned by Weisbach† it was noted that these were strongly pleochroic, the direction of greatest absorption being at right angles to the longest axis of the plates. By continued and higher heating a still further reduction took place and metallic germanium was deposited as a crystalline sublimate on the walls of the tube. Microscopic examination showed this sublimate to consist of small gray-white octahedral crystals of magnificent metallic luster. They were found to be insoluble in hydrochloric acid but were readily dissolved by aqua regia. These results agree exactly with those given by Winkler, and the identity was still further confirmed by the entire behavior of the element and by other results which will be given in the course of this article.

The physical properties of this new mineral are as follows: Crystallization isometric. Among the specimens furnished by Mr. Canfield were two which were well crystallized. One of these consisted of a group of unmistakable octahedral crystals, averaging about 7 mm. in axial diameter, but which were too rough for measurement on the goniometer. Their edges were sometimes truncated by the dodecahedron, while some were twinned about an octahedral face. The other specimen contained equally large but less isolated crystals, the luster of whose faces was good and one of the crystals, showing the

* Journ. f. prakt. Chem., xxxiv, 1886, p. 177.

† Quoted by Winkler, loc. cit., p. 215.

four upper faces of an octahedron, with edges truncated by the dodecahedron was measured on the reflecting goniometer as follows:

$$111 \wedge \text{I}11 = 70^\circ 0'$$

$$\text{I}11 \wedge \text{II}1 = 70^\circ 29'$$

$$\text{II}1 \wedge \text{I}11 = 70^\circ 14'$$

$$\text{I}11 \wedge 111 = 70^\circ 8'$$

$$\text{Calculated } 70^\circ 32'$$

$$111 \wedge \text{II}1 = 108^\circ 57'$$

$$\text{I}11 \wedge \text{I}11 = 109^\circ 3'$$

$$\text{Calculated } 109^\circ 28'$$

The reflections of the signal were moderately good and considering a slight rounding of the faces the measurements agree as closely with those of the octahedron as could be expected. The dodecahedral faces were too uneven to yield a distinct reflection. These crystals were tested and found to give the characteristic reactions for germanium. The fracture is irregular to small conchoidal. Extremely brittle. Hardness about 2.5. The specific gravity of two distinct, massive fragments, weighing about five and six grams each, carefully taken on a chemical balance after boiling in distilled water, was found to be 6.2662 and 6.2657 respectively, the temperature being 25°C . The specific gravity of the fragment containing the crystal that was measured and weighing over 22 grams was found to be 6.270. The luster is brilliant metallic. The color black with a bluish to purplish tone. The streak is grayish black, somewhat shiny. The chief pyrognostic properties have already been given. In addition, the fusibility at about $1\frac{1}{2}$ to 2 should be noted. The fused transparent globules which were observed on charcoal are probably GeO_2 . Some of the oxide separated from the quantitative analysis was tested on charcoal as follows: In the oxidizing flame it fused with bubbling to a transparent, glassy globule, giving no coating. By continued heating in the reducing flame it darkened and gave slowly a pure white sublimate. The yellow coating obtained on charcoal from the mineral was probably a mixture of oxide and sulphide of germanium. The fused globules, which were observed near the assay in the closed tube are GeS_2 or possibly some oxysulphide.

Argyrodite from Freiberg, when tested in the closed tube, gives at first a black sublimate, which, as stated by Richter,* looks exactly like mercuric sulphide and undoubtedly is that substance. On intense heating before the blowpipe there formed farthest up on the tube a sublimate of sulphur, next followed the black ring of mercuric sulphide, neither of which increased perceptibly by continued heating, while nearest the assay the nearly colorless globules of GeS_2 were deposited. On breaking off the lower end of the tube, driving off the sulphur and mercuric sulphide by gentle heat and then roasting the globules in a current of air, SO_2 was given off while the germanium oxide collected into a fused mass but was not volatilized. Regarding the association of canfieldite with other minerals, all that can be said is that the specimens are remarkably pure, only slight quantities of pyrite, sphalerite and kaolin being attached to them.

It having been shown that the mineral was essentially a sulpho-salt of germanium and silver, the following method was adopted for analysis. A weighed quantity, about two grams, was oxidized by concentrated nitric acid, the operation requiring from one to two hours on the water bath. After the oxidation was complete the excess of nitric acid was removed by evaporation. The residue was then dissolved in warm water slightly acidified with nitric acid, and after filtering off a slight trace of insoluble residue the silver was precipitated by hydrochloric acid, filtered, and weighed. In the filtrate the sulphur was precipitated as barium sulphate, which was purified by fusion with sodium carbonate, reprecipitated and weighed. For the determination of germanium another portion of two grams was oxidized by nitric acid with the addition of a little sulphuric acid. After removal of the large excess of nitric acid by evaporation, the residue was dissolved in warm water, with addition of some nitric acid if necessary, the silver precipitated with ammonium thiocyanate and removed by filtration. The filtrate contained the germanium together with no acid which forms with it a

* Quoted by Weisbach and Winkler.

volatile compound. It was evaporated in a platinum dish, the nitric acid present serving to completely destroy the ammonium thiocyanate, and the excess of sulphuric acid was finally driven off by heating. The residue thus obtained was covered with a little strong ammonia into which hydrogen sulphide was conducted. Under this treatment the germanium oxide dissolved, while all heavy metals, except those which form sulphy-salts soluble in ammonium sulphide, were left undissolved. In this particular case a very small quantity of a black sulphide remained; it was filtered off, ignited and weighed. It is assumed to be a mixture of zinc and iron oxides, resulting probably from admixed sphalerite and pyrite. The filtrate containing the germanium was collected in a weighed platinum crucible and evaporated on the water bath. The residue was oxidized by strong nitric acid, the excess of which was removed by evaporation. The crucible, placed inside a porcelain one, was then ignited, gently at first, finally to the full extent of a ring burner, then weighed, and the germanium determined as GeO_2 . On further ignition the weight was found to be constant, nor did it change by heating to full redness. When heated in a current of ammonia and air, to remove sulphuric acid, the weight diminished very little; thus in one experiment it fell from 0.1535 to 0.1525 grams, showing that a gentle ignition is sufficient to practically expel all of the sulphuric acid. By heating to a bright redness in a current of ammonia and air the germanium oxide suffered reduction to the metallic state. To show that the germanium oxide was pure and especially to prove the absence of arsenic and antimony the following tests that were made may be mentioned. Rather large quantities of the mineral, when roasted in the open tube gave no sublimate. An acid solution of the oxide gave upon addition of hydrogen sulphide a white precipitate, which when collected on a filter showed only a pale tinge of yellow. Also the oxide obtained in the analysis when dissolved and brought into a Marsh apparatus gave only a most minute and unweighable blackening on the walls of the tube, which on ignition in the

air changed to a scarcely perceptible white oxide resembling antimony. As the mineral dissolves completely in nitric acid tin cannot be present. These results therefore showed that the germanium was satisfactorily pure. Another method of analysis in which everything was determined in one portion is as follows: Solution of the mineral in nitric acid, precipitation of the silver with hydrochloric acid, of the sulphur with barium nitrate, removal of the excess of chlorine and barium in one operation with silver nitrate and sulphuric acid, final removal of the silver by ammonium thiocyanate and determination of the germanium in the filtrate as above.

The result of the analysis gave the following figures:

				Average.	Deducting Theory for impurities. Ag_3GeS_6 .	
S	17.03	17.04	...	17.04	17.10	17.06
Ge	6.51	6.52	6.61	6.55	6.57	6.42
Ag	76.01	76.09	...	76.05	76.33	76.52
Fe, Zn	0.14	0.16	0.10	0.13	...	...
Insol.	0.29	...	...	0.29	...	...
				100.06	100.00	100.00

The formula of the mineral is evidently Ag_3GeS_6 or $4\text{Ag}_2\text{S} \cdot \text{GeS}_2$. The agreement of the analysis with the theory, as will be noticed, is reasonably close.

Winkler made the following analysis of the Freiberg argyrodite, from which he derived the formula Ag_3GeS_6 or $3\text{Ag}_2\text{S} \cdot \text{GeS}_2$.

	Analysis by Winkler.	Theory for Ag_3GeS_6 .	Theory for Ag_3GeS_6 .	Atomic weights.
S	17.13	18.21	17.06	32
Ge	6.93	8.23	6.42	72.32
Ag	74.72	73.56	76.52	107.7
Hg	0.31	...	...	...
Fe	0.66	...	...	...
Zn	0.22	...	...	...
	99.97	100.00	100.00	

It will be noticed that Winkler's analysis agrees much more closely with the theory for Ag_3GeS_6 , especially in respect to the sulphur and germanium, than with the formula

advanced by him. It seems probable, therefore, that the two minerals have the same chemical composition, but since Weisbach has shown that argyrodite is monoclinic and since canfieldite is isometric, they cannot be identical.*

In order to investigate this point more closely it seemed desirable to make a new analysis of argyrodite by the same methods which had been used for canfieldite. The material was very carefully selected from an excellent specimen of the Freiberg argyrodite in the collection of Professor Brush. The specific gravity was determined in two ways. Some larger fragments, weighing about two grams, gave on the chemical balance in distilled water 6.149 and the smaller ones gave by use of the pycnometer 6.162. These results, though somewhat higher than those given by Winkler and Weisbach, which were 6.085–6.111, are still considerably lower than the specific gravity of canfieldite. The results of the analysis are as follows:

			Average.
S	16.97	. . .	16.97
Ge	6.67	6.62	6.64
Ag	75.57	75.53	75.55
Hg	0.34	. . .	0.34
Fe, Zn . . .	0.24	. . .	0.24
			99.74

It will be seen that this analysis agrees remarkably well with that of Winkler, the only essential difference being that the silver is somewhat higher and the iron and zinc are lower. This suggests that these latter are impurities, resulting from the presence of a slight admixture of pyrite and sphalerite, both of which are associated with the mineral. In regard to the mercury, since this element has never been known to occur otherwise at Freiberg, it is probable that it replaces silver. If we now recalculate these analyses, excluding the iron and zinc with sufficient sulphur to form pyrite and

* Compare note at the beginning of this article, page 198.

sphalerite, and replacing the mercury by its equivalent in silver, we obtain the following:

Canfieldite.	Argyrodite, Winkler.	Argyrodite, Author.	Theory for Ag_8GeS_6 .
17.10	16.56	16.83	17.06
6.57	7.05	6.69	6.42
76.33	76.39	76.48	76.52
<u>100.00</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>

From the consideration of these results there can be no doubt that canfieldite and argyrodite have the same chemical composition, which is Ag_8GeS_6 . It is evident therefore that we have here a case of dimorphism, for both the crystalline forms and the specific gravities indicate that the minerals are distinct.

ON THE CHEMICAL COMPOSITION OF STAUROLITE, AND THE REGULAR ARRANGEMENT OF ITS CARBONACEOUS INCLUSIONS.

By S. L. PENFIELD AND J. H. PRATT.

(From Amer. Jour. Sci., 1894, vol. 47, pp. 81-89.)

Historical. — In the early analyses of staurolite, especially those of Jacobson * and Rammelsberg,† a great variation was found in the chemical composition, especially in the amounts of silica, which varied all the way from 27 to 50 per cent. The iron oxide, moreover, was regarded by some investigators as ferric, by others as ferrous, while still others considered that it existed in both states of oxidation.

In 1865 Lechartier ‡ observed that pulverized staurolite from Brittany and Bolivia, when examined with the microscope, showed both brown and colorless grains. On treatment with hydrofluoric acid, it was found that the colorless ones dissolved, while the staurolite was very slightly attacked. Furthermore, material purified by this treatment was found to be nearly uniform in specific gravity and gave amounts of SiO_2 varying from 28-29 per cent, agreeing with the purest staurolite from St. Gothard. He also proved that water was an essential constituent of the mineral.

In 1872, Von Lasaulx § showed, from a microscopic examination of staurolite from various localities, that all crystals are more or less impure from mechanical admixtures, especially of quartz, while garnet, cyanite, magnetite and mica were also observed. These inclusions of quartz, amounting sometimes to 30-40 per cent of the total weight of the crys-

* Pogg. Ann., lxii, p. 419, 1844, and lxxviii, p. 414, 1846.

† Pogg. Ann., cxiii, p. 599, 1861. ‡ Bull. Soc. Chimique, iii, p. 378.

§ Min. Mittheilung, 1872, p. 173.

tals, account for the great variation of the silica percentages in the older analyses.

In 1873 Rammelsberg * re-examined the exceptionally pure staurolite from St. Gothard and also the impure material from Pitkäranta and Brittany, in which he had previously found over 50 per cent of silica. After purifying these latter by treatment with hydrofluoric acid, only from 29 to 30 per cent of silica was found and the analyses agreed with that of the St. Gothard mineral. From these analyses he deduced the formula $H_2Fe_3Al_{12}Si_6O_{34}$, the iron being regarded as ferrous and replaced in part by magnesia.

In 1885 Friedl † investigated carefully selected material from St. Gothard and Tramnitzberg in Mähren, which by examination with the microscope had been found to be free from foreign inclusions. From the results of his analyses he deduced the formula $H_4Fe_6Al_{24}Si_{11}O_{66}$. In the same year Coloranio ‡ analyzed the St. Gothard staurolite, which had been carefully selected and digested with hydrofluoric acid, the formula deduced by him being $H_2Fe_2Al_{12}Si_5O_{31}$.

It is interesting to note the variations in the proposed formulæ, each investigator in turn finding a smaller amount of silica, as shown below, where the formulæ of Rammelsberg and Coloranio have been doubled for more ready comparison.

Rammelsberg	$H_4Fe_6Al_{24}Si_{12}O_{68}$
Friedl	$H_4Fe_6Al_{24}Si_{11}O_{66}$
Coloranio	$H_4Fe_4Al_{24}Si_{10}O_{62}$

From a consideration of the analyses of Friedl and Coloranio, Groth § concludes that staurolite has a still simpler formula, and suggests a basic orthosilicate $(AlO)_4(AlOH)Fe(SiO_4)_2$.

Selection and preparation of material for analysis. — In the present investigation, material of exceptional purity was selected from the four following localities: St. Gothard,

* Zeitschr. Deutsch. geol. Gesell., xxv, p. 53.

† Zeitschr. Kryst., x, p. 366.

‡ Bull. Soc. Chimique, xlv, p. 427.

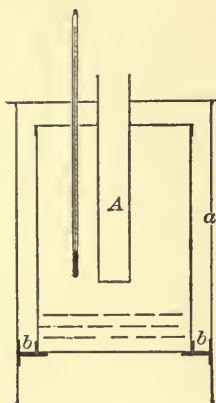
§ Tabellarische Uebersicht der Mineralien, 1889, p. 104.

Switzerland; Windham, Maine; Lisbon, New Hampshire, and near Burnsville, North Carolina. The material from the first of these is too well known to need special description. Some crystals from the Brush collection were available. At Windham, Maine, it occurs in crystals measuring up to 25 mm. in diameter, imbedded in mica schist, as represented by an excellent suite of specimens in the Brush collection. This has never been previously analyzed. The material from Sugar Hill in Lisbon, N. H., was collected in the summer of 1893 by Professor Brush. As observed by him, extensive ledges of gray staurolitic mica schist occur, extending several miles north from Pearl Lake, better known as Mink Pond, and including the ledges on Garnet Hill and Cowen Hill. In the ledges on Cowen Hill unusually large and fresh crystals are found measuring up to 115 mm. long by 40 mm. broad. Thin sections of these crystals revealed the fact that they are remarkably free from inclusions of quartz and garnet, which are so common in staurolite, but they contain carbonaceous material arranged in certain definite planes, as described later. The staurolite from near Burnsville was collected by the writers in the summer of 1892, while engaged in work for the North Carolina Geological Survey. It was found at and near a prospect pit on the property of Mr. D. M. Hampton, which had been dug in exploiting for iron ore. The associated minerals are magnetite, menaccanite, and corundum. The staurolite occurs in crystalline aggregates, often intimately associated with the iron ores.

In the preparation of material for analysis the carefully selected crystals were pulverized and sifted to a uniform grain. In the case of the North Carolina mineral the magnetite and menaccanite were removed by means of an electro-magnet. In order to separate a powder of uniform specific gravity the use of fused silver nitrate, which may be diluted with potassium nitrate, was resorted to, as recommended by J. W. Retgers.* It was found convenient to use a double-walled, cylindrical copper air bath, shown in section in the accom-

* Jahrb. für Min., 1889, ii, p. 190.

panying figure. The outer cylinder *a* stands on legs which are not represented. The inner bath is supported by brackets,



b, and is provided with several perforated discs near the bottom, which serve to disseminate the heat of the lamp. The well *A* holds a test tube containing the silver nitrate, which can readily be kept in a state of fusion and at a constant temperature for any desired length of time; this latter condition being very essential in order to avoid circulating currents. The fusing point of silver nitrate is 198° C., but the temperature which was found most convenient for work was about 250° C. The specific gravity of fused AgNO_3 is about 4.1 which may be lowered by addition of KNO_3 . The

fused salt is a clear mobile liquid, through which the particles of mineral move freely, and separations can be made in this as accurately as in any of the heavy solutions. On cooling, the fusion solidifies to a cake with the heavier and lighter portions at the bottom and top, respectively. The test tube readily breaks away from the fused mass, the cake can be cut in two and the minerals separated by dissolving the nitrates in water. The latter can be reclaimed by evaporating the solutions to dryness on a water bath and finally fusing. By eliminating the heavier and lighter portions and repeating the separation, remarkably pure products were obtained, of nearly uniform specific gravity. The manipulations are very simple and the results extremely satisfactory. A preliminary experiment that was made showed that staurolite does not suffer any decomposition or loss in weight when exposed to a temperature of 250° C. The separated material, when examined with the microscope, was found to be homogeneous and very free from visible inclusions.

Method of analysis. — The silica and bases were determined by well known methods. The evaporations were carried on

in platinum, the purity of the silica tested by evaporation with hydrofluoric acid and account taken of the small quantity of silica carried along and weighed with the sesquioxides. Especial care was taken in the determination of ferrous and ferric iron. The very finely pulverized mineral was treated in a small platinum bottle with a mixture of strong hydrofluoric and sulphuric acids and boiled vigorously for about twenty minutes, the neck of the bottle being covered by a cone of platinum foil. The contents of the bottle were then diluted with cold boiled water, washed into a casserole and titrated with potassium permanganate. Preliminary experiments were made by treating known weights of ferrous sulphate in the same manner and it was found that no appreciable oxidation from the air took place. As the staurolite is very slowly attacked by hydrofluoric acid only a portion in each experiment went into solution. After titration, the insoluble portion was filtered off and the filtrate evaporated in a platinum dish till all the hydrofluoric acid was expelled. After diluting, the iron was reduced by hydrogen sulphide, the excess of the latter removed by boiling and the total iron determined by means of potassium permanganate. The determinations give the ratio of ferrous to ferric iron in that portion which had been dissolved by the hydrofluoric acid, and the total iron in the mineral having been previously found in the portion used for silica and bases, the percentages of ferrous and ferric iron are readily calculated. Direct determinations of water were made in all cases, as loss by ignition would naturally give too low results, owing to the oxidation of the ferrous iron.

Analytical results. — The results of the analyses are given below, together with the specific gravity determinations which were made very carefully by means of the pycnometer.

St. Gothard, Switzerland.

Specific gravity = 3.748.

	I.	II.	Average.
SiO ₂	27.80	27.65	27.73
Al ₂ O ₃	53.23	53.35	53.29
Fe ₂ O ₃	2.83	2.83	2.83
FeO	11.21	11.20	11.21
MnO	0.63	0.44	0.53
MgO	1.77	1.85	1.81
H ₂ O	2.19	...	2.19
			99.59

Windham, Maine.

Specific gravity = 3.728.

	I.	II.	III.	Average.
SiO ₂	27.81	27.88	...	27.84
Al ₂ O ₃	54.44	54.51	54.36	54.46
Fe ₂ O ₃	2.81	2.90	2.80	2.83
FeO	10.52	10.85	10.44	10.60
MnO	0.59	0.62	0.56	0.59
MgO	1.83	1.87	...	1.85
H ₂ O	2.24	...	...	2.24
				100.41

Lisbon, New Hampshire.

Specific gravity = 3.775.

SiO ₂	27.81
Al ₂ O ₃	54.09
Fe ₂ O ₃	2.76
FeO	12.48
MgO	1.92
H ₂ O	1.70
	100.76

Burnsville, North Carolina.

Specific gravity = 3.773.

	I.	II.	III.	IV.	Average.
SiO ₂	27.80	27.65	27.59	27.77	27.70
Al ₂ O ₃	53.09	53.30	...	53.27	53.22
Fe ₂ O ₃	4.81	4.81	4.83	4.85	4.82
FeO	9.70	9.68	9.74	9.79	9.72
MnO	0.27	0.38	0.33	0.36	0.34
MgO	2.64	2.65	2.70	...	2.66
H ₂ O	1.99	1.96	...	...	1.97
					100.43

For a better comparison of the results the average analyses are given below, after recalculating Fe_2O_3 as Al_2O_3 , MnO and MgO as FeO and bringing the whole to one hundred per cent.

	St. Gothard, Switz.	Windham, Me.	Lisbon, N. H.	Burnsville, N. C.
SiO_2	27.70	27.60	27.44	27.47
Al_2O_3	55.04	55.75	55.16	55.83
FeO	15.07	14.43	15.72	14.74
H_2O	2.19	2.22	1.68	1.96
	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>

The ratios in these analyses are as follows:

	$\text{SiO}_2 : \text{Al}_2\text{O}_3 : \text{FeO} : \text{H}_2\text{O}$
St. Gothard	0.460 : 0.540 : 0.209 : 0.121 = 2.12 : 2.50 : 0.967 : 0.560
Windham	0.460 : 0.546 : 0.200 : 0.122 = 2.11 : 2.50 : 0.915 : 0.557
Lisbon	0.457 : 0.540 : 0.218 : 0.093 = 2.11 : 2.50 : 1.01 : 0.430
Burnsville	0.458 : 0.547 : 0.205 : 0.109 = 2.07 : 2.50 : 0.934 : 0.497

The above ratios approximate closely to 2 : 2.5 : 1 : 0.5 which would give the formula $\text{HAl}_5\text{FeSi}_2\text{O}_{13}$, in which the aluminium is partly replaced by ferric iron and the ferrous iron by magnesium and manganese. This is, moreover, the formula suggested by Groth, and, as previously stated, may be written as a basic orthosilicate, $(\text{AlO})_4(\text{AlOH})\text{Fe}(\text{SiO}_4)_2$ or equally well, $(\text{AlO})_4\text{Al}(\text{FeOH})(\text{SiO}_4)_2$. The percentage composition required by the formula is the following:

SiO_2	26.32
Al_2O_3	55.92
FeO	15.79
H_2O	1.97
	<u>100.00</u>

From a comparison of the ratios, or of the analyses as reduced, with the theory, it will be observed that the silica is uniformly a trifle high, amounting to something over one per cent. This cannot be referred to an analytical error, as the distilled water and reagents were pure, and platinum vessels were used for the evaporations. It was not derived from the agate mortar in which the mineral was ground, for in the

analysis of the mineral from Lisbon a steel mortar was used, the powder being afterwards purified by treatment with hydrochloric acid. From the careful selection of nearly pure mineral to start with, and the special precautions that were taken to eliminate all heavier and lighter portions by the specific gravity separation, it was not expected that the staurolite grains would still contain inclusions of quartz, nor were they visible in the fragments, when examined with the microscope; from the results of the analyses, however, it is evident that they were not wholly eliminated. To test this point more carefully, the following experiments were made on some of the finely powdered minerals left over from the regular analyses. After digesting with cold, strong hydrofluoric acid for twelve hours and washing, silica determinations were made, which are given below, along with the determinations from the previous analyses.

	St. Gothard.	Windham, Me.	Lisbon, N. H.
SiO ₂ after treatment with HF,	27.52	27.36	27.15
SiO ₂ from regular analyses	27.73	27.84	27.81

It will be observed that hydrofluoric acid has removed some silica, but still the percentages are higher than the theory. We should infer, therefore, that quartz is an impurity in the mineral and that it is present as very minute inclusions. If, for example, the inclusions are as fine or finer than the acicular crystals of rutile in quartz, they could not be removed by a specific gravity separation, nor, being enclosed in the staurolite, would they be wholly accessible to the action of hydrofluoric acid. That the formula suggested by Groth is correct is well established by our analyses and, surely, its simplicity is one of the strongest arguments that can be advanced for its acceptance.

On the regular arrangement of inclusions in staurolite crystals. — In examining orientated thin sections of crystals from Lisbon, N. H., it was observed that they all contained dark inclusions, arranged in certain definite planes, resembling the phenomena so common in andalusite. That the inclu-

sions are carbonaceous material was proved by the fact that, on separating the pulverized mineral by specific gravity, the dark portion was found to be lighter than the clear staurolite, and on igniting it in a current of air, purified by passing over caustic potash, carbon dioxide was abundantly evolved. These inclusions can only be clearly seen in plates ground sufficiently thin to be transparent and can best be studied in basal sections.



FIGURE 1.



FIGURE 2.

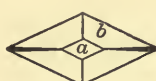


FIGURE 3.

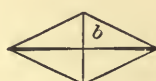


FIGURE 4.

Figures 1 to 4 represent the arrangement of the inclusions in plates cut from a simple prismatic crystal 50 mm. in length by 11 mm. broad from which eleven basal sections were cut. Near the ends the impurities are arranged as in Figure 1; at the middle the appearance is that of a simple dark cross, Figure 4; while intermediate sections show the rhomb diminishing in size as the sections approach the middle of the crystal, Figures 2 and 3. A number of crystals were cut showing these same phenomena and the symmetrical arrangement of the rhomb and cross was always well marked. The central portions *a* and the outer ones *b*, up to the very edges of the section, are remarkably pure staurolite. The dark bars running parallel to the macro-axis broaden as they approach the outer angle of the section and are more regular and better defined than the brachy-diagonal ones. From a series of sections, then, it is evident that each staurolite prism contains two skeleton or phantom pyramids, *P*, outlined by carbonaceous material, whose bases correspond to the basal planes of the staurolite and whose apices join at the center, while from the acute and obtuse pole edges of the pyramids the inclusions extend as films or fins *A* and *B* to the vertical edges of the prism, Figure 5, the numbers at the side of the figure indicating where sections should be cut to give the phenomena

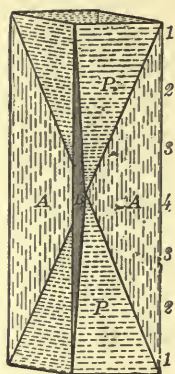


FIGURE 5.

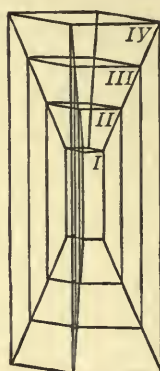


FIGURE 6.

corresponding to Figures 1 to 4 respectively. Regularly arranged inclusions have previously been observed in staurolite,* but apparently they have never been studied from a series of sections from a single crystal.

In seeking for an explanation of these inclusions, it must be borne in mind that staurolite is a mineral occurring essentially in the crystalline schists, which were probably derived from former mud or clay deposits. The crystals were formed by metamorphic agencies, under great pressure, in rocks which were probably quite firm and solid while the staurolite was forming. The crystals, therefore, must have exerted great force in crowding away the surrounding rock material in order to make room for their growth, and we must take into consideration their inability to exclude foreign matter under these conditions, as well as their tendency to take it up. Large crystals have surely resulted from a growth about smaller ones and the beginnings of the crystals under consideration were undoubtedly at the centers, where the apices of the pyramids, P, Figure 5, join. In the development of a large crystal from a small one it is imagined that at various

* C. T. Jackson, *Alger's Phillips Mineralogy*, 1844, p. 112; Dana's *Min.*, Sixth edition, p. 560; S. Webber, *Proc. Nat. Institution for the Promotion of Sci.*, Bull. 2, p. 197, 1842; A. Lacroix, *Min. de la France*, 1893, p. 11.

points on the crystal faces the growth commences. The addition of particles or of crystal molecules must then advance, forcing foreign matter to one side until the crystal surfaces are complete. The particles, however, which meet to form the edges of the crystals may come together in such a way that they cannot exclude certain foreign materials. It would, moreover, seem reasonable to expect that the more obtuse the angle at which the faces, or the crystal molecules forming the faces, meet to form an edge, the less tendency there would be to hold impurities, while the more acute the edge the greater this tendency would become. If these conclusions are correct, then inclusions would be taken up by the edges, and being largely of carbonaceous material, as in the staurolite under consideration, the result would be that, in the development of a large crystal from a smaller one, the inner prism I, Figure 6, as it enlarged to form II, III, IV, would leave a dark deposit along the paths described by its advancing edges, corresponding to the planes A, B and P of Figure 5. In examining many basal sections it has, moreover, been generally observed that the bars running parallel to the macro-axis, representing the impurities taken up at the acute edges of the prism, are the heaviest, those parallel to the brachy-axis are the lightest and in some sections practically fail, while the outlines of the inner rhomb, representing the impurities taken up along the edges of 90° between prism and base, are intermediate as regards the quantity of included matter. Also the inclination of the phantom pyramid, P, Figure 5, seems to be wholly dependent upon the relative development of the prism and base during the growth of the staurolite crystal and to be in no way connected with the length of the vertical axis as expressed by the axial ratio $a : b : c$.

The considerations given above seem sufficient to account for the curious arrangements of the impurities in the crystals under consideration and doubtless by a similar explanation the impurities in some andalusite crystals could be accounted for.

ON THE CHEMICAL COMPOSITION OF CHONDRODITE, HUMITE, AND CLINOHUMITE.

BY S. L. PENFIELD AND W. T. H. HOWE.*

(From Amer. Jour. Sci., 1894, vol. 47, pp. 188-206.)

Introduction.—These minerals, which are regarded collectively as the humite group, have been the subject of repeated crystallographic and chemical investigation. For our knowledge of their crystallization we are indebted to such careful and accurate observers as Haüy, Phillips, G. Rose, Lévy, Miller, Hausmann, Hessenberg, A. Scacchi, vom Rath, Nordenskiöld, Kokscharow, J. D. and E. S. Dana, C. Klein, Des Cloizeaux and Hj. Sjögren, whose names are familiar to all workers in crystallography and mineralogy. It is not the purpose of this article to take up the details of the crystallization of these minerals nor to review the progressive steps by means of which we have derived our present knowledge of their highly modified and complicated crystalline structure, but reference may be made to the excellent historical sketch in the recent edition of Dr. Hintze's Mineralogy, page 370. In the description of the crystals that were examined during the course of our investigation we shall use essentially the same system of lettering and of crystal notation adopted by A. Scacchi † and E. S. Dana.‡

In the humite group three distinct species are at present recognized, each characterized by the occurrence of certain forms which are not found on the others and having the following axial relations:

* This article has been somewhat shortened by omitting both the descriptions of methods employed in preparing materials for analysis and the discussions of analyses made by other investigators. — EDITOR.

† Pogg. Ann., Erg. B., iii, p. 161, 1851.

‡ Mineralogy, sixth edition, p. 535. Trans. Conn. Acad., iii, p. 67.

Chondrodite, Monoclinic	$a : b : c = 1.08630 : 1 : 3.14472$	$\beta = 90^\circ$ *
Humite, Orthorhombic	$a : b : c = 1.08021 : 1 : 4.40334$	$\beta = 90^\circ$ †
Clinohumite, Monoclinic	$a : b : c = 1.08028 : 1 : 5.65883$	$\beta = 90^\circ$ ‡

In the above the a axes are practically alike, while, as shown by Scacchi and vom Rath, a simple relation exists between the vertical axes, that of chondrodite being $\frac{5}{7}$ ths and that of humite $\frac{7}{8}$ ths the length of the clinohumite axis. These relations are shown in the following table, to which the axial ratio of chrysolite, a closely related mineral, has also been added.

Chondrodite	$a : b : \frac{1}{5}c = 1.08630 : 1 : 0.62894$
Humite	$a : b : \frac{1}{7}c = 1.08021 : 1 : 0.62905$
Clinohumite	$a : b : \frac{1}{8}c = 1.08028 : 1 : 0.62876$
Chrysolite	$b : 2a : c = 1.0735 : 1 : 0.6296$

It is evident from the above that the first three minerals form a crystallographic series and that all of the forms occurring on them could practically be referred to one system of axes, but by so doing the parameter relations on the vertical axis would become exceedingly complicated. Chondrodite and clinohumite, although their inclination β is 90° , are monoclinic both as regards the symmetry in the development of the faces and their optical properties, chondrodite showing an extinction of 26° – 30° and clinohumite $7\frac{1}{2}^\circ$ – $12\frac{1}{2}^\circ$ from the vertical axis, while humite in all of its properties is orthorhombic.

The chemical relations of the minerals have never been satisfactorily determined. This is owing partly to the fact that it has been difficult to obtain pure materials in sufficient quantity for analysis, while the analytical difficulties in the accurate determinations of silica and fluorine have not always been overcome. Water in the form of hydroxyl, which is an unfailing constituent of the minerals, has either been

* E. S. Dana, loc. cit.

† A. Scacchi, loc. cit.

‡ Vom Rath, Pogg. Ann., Erg. B., v, p. 373, 1871.

overlooked or incorrectly determined. Scacchi* regarded the minerals as representing three types of crystallization of one and the same chemical substance, which he designated as humite type I, type II and type III. Rammelsberg† and vom Rath‡ have suggested for the whole group the formula $Mg_5Si_2O_9$, with part of the oxygen replaced by fluorine, although they recognized that the percentages of silica varied in the different types. Wingard§ also, from the results of his recent analyses, concludes that the three minerals have the same chemical composition, expressed by the formula $Mg_{19}F_4(OH)_2Si_8O_{38}$, while Hj. Sjögren,|| largely from a recalculation of the older analyses and a consideration that water had been overlooked in them, derived a separate formula for each species, as follows:

Clinohumite	$Mg_5[Mg(OH, F)]_2 [SiO_4]_3$
Humite	$Mg_8[Mg(OH, F)]_2 [SiO_4]_2$
Chondrodite	$Mg_4[Mg(OH, F)]_4 [SiO_4]_3$

Sjögren assumes that hydroxyl is isomorphous with fluorine, and calls attention to the fact, already suggested by Rammelsberg and vom Rath, that the three minerals show a variation in their silica percentages.

In the present investigation we have been able to examine the following materials: Chondrodite from Warwick and Brewster's, New York; Kafveltorp, Sweden, and Mte. Somma, Italy. Humite and clinohumite from Mte. Somma.

After having definitely determined the crystallographic character of the minerals they were pulverized and sifted to a uniform grain and separated from the gangue and other impurities by means of the barium-mercuric-iodide solution. Thanks to this accurate method of separation, we have had an advantage over all previous investigators in being able to

* Loc. cit.

† Mineralchemie, p. 434, 1875.

‡ Pogg. Ann., cxlvii, p. 254, 1872.

§ Zeitschr. Anal. Chem., xxiv, p. 344, 1885.

|| Zeitschr. Kryst., vii, p. 354, 1883.

obtain an abundance of material for the chemical analyses. Each product that was obtained was nearly uniform in specific gravity and almost absolutely pure, as shown by examination with the polarizing microscope.

CHONDRODITE (*Humite Type II of Scacchi*).

Chondrodite from Warwick, Orange Co., N. Y. — The material that was selected for analysis was obtained from a specimen in the Brush collection, Catalogue No. 2054. The chondrodite occurs as rounded grains, of a rich reddish-brown color imbedded in a white crystalline limestone and associated with spinel and graphite. The material was very fresh and showed occasional crystal faces, but not sufficient for the identification of the mineral. It was selected at the beginning of our investigation, as it afforded abundant material for testing the methods of the mechanical separation and the chemical analysis. The powder separated by the heavy solution varied in specific gravity between the limits 3.165 and 3.235. It showed only a trace of impurities when examined with the microscope, probably of partly altered spinel, which accounts for the small amount of Al_2O_3 shown by the analysis. That the mineral is really chondrodite is proved by the chemical analysis, as will be shown later, while from the same locality there is in the Brush collection a small specimen, Catalogue No. 2057, corresponding exactly in color and showing crystals that could be measured and identified as chondrodite. These are associated with an ash-gray amphibole and have evidently weathered out from limestone.

Chondrodite from the Tilly Foster mine, Brewster, Putnam Co., N. Y. — The material for analysis was selected wholly from isolated crystals, which were obtained by the present writers at the locality. Each crystal was measured and found to possess characteristic chondrodite forms. The habits of different crystals varied considerably but conformed in general to types figured by E. S. Dana.

Chondrodite from Kafveltorp, Sweden. — The material for

our investigation was obtained from a specimen in the Brush collection, Catalogue No. 2040. The crystals have a yellowish brown color, are imbedded in sulphides, and their habit as well as this unusual association agree exactly with the description given by Hj. Sjögren; the accompanying minerals being chiefly galena and sphalerite with a little chalcopyrite and amphibole.

Chondrodite from Mte. Somma, Italy.—Our material was selected from a specimen in the Brush collection, Cat. No. 2063, which had been presented to Prof. Brush by Prof. A. Scacchi. The associated minerals constituting the gangue are calcite and biotite (meroxene). The crystals are honey-yellow in color, and transparent.

The analyses are as follows :

Warwick, N. Y.

Specific gravity = 3.168–3.235.

	I.	II.	III.	IV.	Average.	Ratio.	
SiO ₂	33.85	33.67	33.82	33.86	33.80	0.563	0.563
MgO	55.74	55.87	55.78	55.68	55.70	1.396	} 1.433
FeO	2.59	2.64	2.69	...	2.64	0.037	
Al ₂ O ₃	1.79	1.87	...	...	1.83	...	} 0.546
F	7.32	7.26	7.32	...	7.30	0.384	
H ₂ O	1.43	1.48	...	...	1.46	÷ 9 = 0.162	
					102.73		
Oxygen equivalent to F =					3.07		
					99.66		

Brewster, N. Y.

Specific gravity = 3.204–3.231.

	I.	II.	III.	Average.	Ratio.		
SiO ₂	33.66	33.48	33.87	33.67	0.561	0.561	
MgO	54.68	54.92	54.78	54.79	1.370	} 1.452	
FeO	5.89	5.96	5.99	5.94	0.082		
F	5.25	5.38	5.31	5.30	0.279	} 0.593	
H ₂ O	2.60	2.44	2.61	2.55	÷ 9 = 0.294		
				102.25			
Oxygen equivalent to F =				2.23			
				100.02			

Kafveltorp, Sweden.

Specific gravity = 3.252-3.265.

	I.	II.	III.	IV.	Average.	Ratio.	
SiO ₂	33.36	33.28	33.18	33.52	33.33	0.556	0.556
MgO	54.23	54.37	...	...	54.30	1.358	} 1.450
FeO	6.66	6.58	...	...	6.62	0.092	
F	6.74	6.58	6.63	6.43	6.60	0.347	} 0.533
H ₂ O	1.63	1.72	...	...	1.67	÷ 9 = 0.186	
					102.52		
Oxygen equivalent to F =					2.76		
					99.76		

Mte. Somma, Italy.

Specific gravity = 3.194-3.215.

	I.	II.	Average.	Ratio.	
SiO ₂	33.96	33.78	33.87	0.564	0.564
MgO	56.37	56.55	56.46	1.411	} 1.461
FeO	3.72	3.60	3.66	0.050	
F	5.09	5.21	5.15	0.271	} 0.584
H ₂ O	2.92	2.72	2.82	÷ 9 = 0.313	
			101.96		
Oxygen equivalent to F =			2.16		
			99.80		

In discussing the above analyses it has been assumed that FeO is isomorphous with MgO and hydroxyl with fluorine. The ratios have been collected together in the following table:

	SiO ₂	:	(MgO + FeO)	:	(F + OH)
Warwick,	0.563	:	1.433	:	0.546 = 1.96 : 5 : 1.90
Brewster,	0.561	:	1.452	:	0.593 = 1.93 : 5 : 2.04
Kafveltorp,	0.556	:	1.450	:	0.533 = 1.92 : 5 : 1.84
Mte. Somma,	0.564	:	1.461	:	0.584 = 1.93 : 5 : 1.99

These all approximate to SiO₂ : RO : (F + OH) = 2 : 5 : 2, which would give for the formula of chondrodite, Mg₅[F,OH]₂Si₂O₈ or an isomorphous mixture of the molecules Mg₅[MgF]₂[SiO₄]₂ and Mg₅[MgOH]₂[SiO₄]₂. The ratio of fluorine to hydroxyl, or of the two foregoing molecules, varies consid-

erably. In the Brewster and Mte. Somma minerals it is nearly 1 : 1, in Kafveltorp 2 : 1, and in Warwick $2\frac{1}{3}$: 1. The specific gravities are very close, varying only between 3.165 and 3.265 and, as would be expected, increase with the percentage of iron.

For a better comparison of the analyses with the theory they are given below after recalculating FeO as MgO and bringing the total to one hundred per cent.

	Brewster.	Mte. Somma.	Theory where F : OH = 1 : 1.
SiO ₂	34.56	34.52	35.29
MgO	59.69	59.56	58.82
F	5.44	5.25	5.59
H ₂ O	2.62	2.88	2.65
	102.31	102.21	102.35
O. eq. to F =	2.31	2.21	2.35

	Warwick.	Kafveltorp.	Theory where F : OH = 2 : 1.
SiO ₂	34.91	34.42	35.22
MgO	59.23	59.90	58.71
F	7.54	6.81	7.44
H ₂ O	1.51	1.73	1.76
	103.19	102.86	103.13
O. eq. to F =	3.19	2.86	3.13

These analyses are all slightly high in magnesia and correspondingly low in silica and (F + OH), but on the whole they agree very well with the theory.

HUMITE (*Type I of Scacchi*).

In the course of the investigation we have been able to examine only the humite from Mte. Somma, of which two separate samples were analyzed. The material for the first of these was obtained from a specimen purchased from Dr. A. E. Foote of Philadelphia. The humite crystals, which measure from 2–3 mm. in diameter, are nearly colorless and transparent and are associated with spinel and calcite. Their habit corresponds in general to the figure of vom Rath copied

into the sixth edition of Dana's Mineralogy, page 535. The material for the second analysis was selected from a specimen in the Yale College cabinet, catalogue No. 4102. The crystals are associated with calcite and biotite. They are chestnut brown in color, in habit like the ones described above.

FIRST ANALYSIS.

Specific gravity = 3.194–3.201.

	I.	II.	III.	IV.	Average.	Ratio.	
SiO ₂	36.59	36.63	36.63	36.68	36.63	0.6105	
MgO	56.34	56.43	56.59	56.45	56.45	1.411	} 1.444
FeO	2.33	2.43	2.46	2.30	2.35	0.033	
F	3.12	3.06	2.96	. . .	3.08	0.162	} 0.423
H ₂ O	2.42	2.48	. . .	. . .	2.45 ÷ 9 = 0.261		
					100.96		
Oxygen equivalent to F =					1.26		
					99.70		

SECOND ANALYSIS.

Specific gravity = 3.183–3.225.

	I.	II.	Average.	Ratio.	
SiO ₂	36.84	36.63	36.74	0.612	
MgO	56.21	56.42	56.31	1.408	} 1.437
FeO	2.22	2.21	2.22	0.029	
F	3.89	4.02	3.96	0.208	} 0.444
H ₂ O	2.18	2.08	2.13 ÷ 9 = 0.236		
			101.36		
Oxygen equivalent to F =			1.66		
			99.70		

These analyses differ from those of chondrodite in being about 3 per cent higher in silica, and also the ratios are different as shown by the following:

	SiO ₂	: (MgO + FeO) : (F + OH)		
1st Analysis,	0.6105	: 1.444	: 0.423	= 2.97 : 7 : 2.05
2d Analysis,	0.612	: 1.437	: 0.444	= 2.99 : 7 : 2.16

These ratios approximate closely to 3 : 7 : 2, indicating that the formula of humite is Mg₅[Mg(F, OH)]₂[SiO₄]₃. The ratio

of F : OH in the first analysis is nearly 2 : 3 and in the second about 1 : 1. We give beyond the theoretical composition for both ratios, together with the analyses in which the FeO has been calculated as MgO and the total brought to 100 per cent.

	First analysis.	Theory where F : OH = 2 : 3.	Second analysis.	Theory where F : OH = 1 : 1.
SiO ₂	37.15	37.53	37.24	37.50
MgO	58.56	58.38	58.27	58.34
F	3.12	3.17	4.02	3.96
H ₂ O	2.48	2.25	2.16	1.87
	<u>101.31</u>	<u>101.33</u>	<u>101.69</u>	<u>101.67</u>
O eq. to F = 1.31		1.33	1.69	1.67

These analyses show a very satisfactory agreement with the theory and we may regard the formula of humite as well established.

CLINOHUMITE (*Humite Type III of Scacchi*).

Of this rare mineral we have been able to examine two specimens from Mte. Somma. For the first analysis the material was derived from a specimen in the Brush collection, catalogue No. 2064, which had been presented by W. Sartorius von Waltershausen. The crystals are light wine yellow, transparent and in habit like the simple crystals figured by vom Rath. The associated minerals are, forsterite, biotite, spinel, calcite and a little vesuvianite.

The specific gravity, when taken with the heavy solution, varied between 3.184 and 3.222 and this being almost identical with that of forsterite the yellow clinohumite crystals had to be separated from the colorless forsterite by hand picking. The specimen only afforded 0.3879 grams of the mineral and the analysis was made on this small portion by fusing the whole with dry sodium carbonate in the Gooch crucible to obtain the water, soaking out the fusion and carrying on the analysis in the usual way. In the course of the analysis an unusual accident occurred. The platinum crucible in which the fusion was made broke, and it was not discovered till, on

soaking out the fusion, it was found to leak. The break was of such a nature that the water determination was not lost and the mechanical loss, caused by the leaking, was slight and, in all probability, evenly distributed on the remaining constituents. It is assumed that the deficiency of the analysis, amounting to about 2 per cent, was caused by this accident, as otherwise the analysis was carried on with more than usual care. The analysis is given beyond under *a* as it stands in the note book and under *b* after distributing the deficiency of 2.28 per cent among all of the constituents except water.

The material for the second analysis was derived from a specimen in the Yale College cabinet, catalogue No. 4143. The crystals are chestnut brown in color and are associated with forsterite, biotite, vesuvianite, and a little calcite.

The material for the analysis had to be selected by hand picking and, when introduced into the heavy solution, showed a specific gravity between the limits 3.219 and 3.258. The analyses are as follows:

FIRST ANALYSIS.					
	<i>a.</i>	<i>b.</i>		Ratio.	
SiO ₂	37.15	38.03	0.634		4.02
MgO	52.74	54.00	1.350	} 1.417	9.00
FeO	4.72	4.83	0.067		
F	2.01	2.06	0.108	} 0.323	2.05
H ₂ O	1.94	1.94 ÷ 9 = 0.215			
	<u>98.56</u>	<u>100.86</u>			
O eq. to F =	0.84	0.86			
	<u>97.72</u>	<u>100.00</u>			

SECOND ANALYSIS.					
				Ratio.	
SiO ₂	37.78	0.629			4.03
MgO	53.05	1.326	} 1.404		9.00
FeO	5.64	0.078			
F	3.58	0.188	} 0.336		2.15
H ₂ O	1.33 ÷ 9 = 0.148				
	<u>101.38</u>				
O eq. to F =	1.50				
	<u>99.88</u>				

In both of these analyses the ratios of $\text{SiO}_2 : \text{RO} : (\text{F} + \text{OH})$ approximate closely to 4 : 9 : 2, corresponding to the formula $\text{Mg}_7[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_4$. In the first analysis, the ratio of $\text{F} : \text{OH} = 1 : 2$ and in the second it is about 1 : 1. Below we have given the analyses after calculating FeO as MgO and bringing them to 100 per cent and, for comparison, the theoretical composition according to the above formula with $\text{F} : \text{OH} = 1 : 2$ and 1 : 1 respectively.

	First analysis.	Theory where $\text{F} : \text{OH} = 1 : 2$.	Second analysis.	Theory where $\text{F} : \text{OH} = 1 : 1$.
SiO_2	38.87	38.75	38.81	38.77
MgO	57.94	58.12	57.64	58.16
F	2.10	2.05	3.68	3.07
H_2O	1.98	1.94	1.37	1.29
	100.89	100.86	101.50	101.29
O eq. to F =	0.89	0.86	1.50	1.29

The agreement of the above analyses with the theory is very satisfactory.

Conclusions.—In the preceding pages we have shown that the minerals of the humite group are *not* identical with each other in chemical composition and that they can be expressed by the following formulæ, constructed on two, three and four molecules of orthosilicic acid, in which two hydrogen atoms are replaced by the univalent radical $[\text{Mg}(\text{F}, \text{OH})]$ and the remaining ones by magnesium:

Chondrodite	$\text{Mg}_3[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_2$
Humite	$\text{Mg}_6[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_3$
Clinohumite	$\text{Mg}_7[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_4$

These form a chemical series, varying progressively from chondrodite to clinohumite by an increase of one molecule of Mg_2SiO_4 . This variation in chemical composition is intimately connected with the crystallization. Thus on page 219 it was mentioned that the three minerals form a crystallographic series in which the vertical axes increase from chondrodite to clinohumite. It was also shown that by dividing the vertical

axes by 5, 7, and 9 respectively the quotients become practically identical and it is a very interesting and remarkable fact that these divisors 5, 7, and 9 correspond to the number of magnesium atoms in the formulæ deduced by us. Groth has shown that in certain organic compounds the substitution of one hydrogen atom by another atom or radical causes a change in one of the crystallographic axes, the other two and the symmetry remaining essentially unchanged. Such a crystallographic series he calls a "Morphotropische Reihe." In the humite group we evidently have a kind of morphotropic series, but not exactly analogous to that cited by Groth, as in the present case we have a change brought about by the *addition* of a molecule of Mg_2SiO_4 , instead of the substitution of a radical. This addition of Mg_2SiO_4 causes the vertical axis to increase by about 1.2575, or $\frac{1}{8}$ of the vertical axis of clinohumite, while the other two axes and the inclination β remain the same. The symmetry, however, changes so that the first and last members of the series are monoclinic. In the whole range of chemical crystallography there is no series of compounds known to the authors that can be compared to the humite group. It is reasonable to expect that other members of this series will be found. Thus $\text{Mg}[\text{Mg}(\text{F}, \text{OH})]_2\text{SiO}_4$ is a possible and a most likely compound to occur. This should crystallize either orthorhombic or monoclinic with $\beta = 90^\circ$ and should have the axial ratio $a : b : c = 1.086 : 1 : 1.887$. The member next beyond clinohumite would be $\text{Mg}_3[\text{Mg}(\text{F}, \text{OH})]_2[\text{SiO}_4]_5$, but, owing to its more complicated composition, it would seem less apt to occur. Chrysolite, Mg_2SiO_4 , is closely related to the members of this group, and, as shown by vom Rath,* a few of its forms are almost identical with those of humite. Their relation is shown on page 219 where the axial ratio $b : 2a : c$ of chrysolite is similar to $a : b : \frac{1}{9}c$ of clinohumite. As chrysolite contains no fluorine or hydroxyl it deviates considerably in its chemical type from the members of the humite group and its crystalline habit is also different, as the majority of its common forms do not

* Pogg. Ann., Ergänz. Band V, p. 412, 1871.

correspond to any of the forms of humite. Of the three species constituting the humite group chondrodite has the simplest composition and is the most common, clinohumite has the most complicated composition and is the rarest, while humite occupies an intermediate position. At Mte. Somma chondrodite, which is the most basic, occurs usually with calcite, while clinohumite, which is the most acid, is usually associated with the silicate forsterite.

The formulæ thus proposed as the result of this investigation are simple and rational, they agree in a very satisfactory manner with the results of our analyses as well as with those of others, and they constitute an extremely interesting chemical series, which is related in a remarkable manner to the crystallization of these minerals.

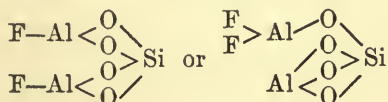
NOTE. — Soon after the publication of this paper Hj. Sjögren (Bull. Geolog. Inst. Upsala, 1894, 2, p. 39) published a series of analyses of the minerals of the chondrodite group confirming the results as set forth in the foregoing pages. He also described a mineral belonging to the group having the ratio of its crystallographic axes $a : b : c = 1.0803 : 1 : 1.8862$. This is supposed to be the possible member of the chondrodite group referred to on the previous page. Although not found in sufficient quantity to admit of a chemical analysis being made, the formula $\text{Mg}[\text{Mg}(\text{F}, \text{OH})]_2\text{SiO}_4$ has been assigned to it. It is named prolectite from *προλέγειν*, to foretell. — EDITOR.

ON THE CHEMICAL COMPOSITION AND RELATED PHYSICAL PROPERTIES OF TOPAZ.

By S. L. PENFIELD AND J. C. MINOR, JR.

(From Amer. Jour. Sci., 1894, vol. 47, pp. 387-396.)

THE chemical composition of topaz has never been satisfactorily settled. The results of the analyses thus far published show clearly that silicon and aluminium are present in the proportion of 1 : 2, but the percentage of fluorine as given in them varies from 16.12-18.83. The formula that is usually accepted is that of Groth * $[\text{Al}(\text{O}, \text{F}_2)] \text{AlSiO}_4$, corresponding to an isomorphous mixture of $[\text{AlF}_2] \text{AlSiO}_4$ with the andalusite molecule $[\text{AlO}] \text{AlSiO}_4$ in which the former predominates and in which fluorine is supposed to be replaced by oxygen. Rammelsberg † suggests a mixture of Al_2SiO_6 and $\text{Al}_2\text{SiF}_{10}$ in the proportion of 5 : 1. The ratio of $\text{SiO}_2 : \text{Al}_2\text{O}_3 : \text{F}$ varies from 1 : 1 : 1.50 to 1 : 1 : 1.84 and if this could be shown to be 1 : 1 : 2 the composition could be expressed by either of the following simple orthosilicate formulæ:



Since it has been shown by one of us that hydroxyl so frequently replaces fluorine, and it now seems very doubtful if bivalent oxygen ever plays this rôle, the idea has suggested itself that perhaps the variations in the percentages of fluorine and the failure to yield a simple ratio are due to the partial

* Tabellarische Uebersicht der Mineralien, 1889, p. 106.

† Mineralchemie, 1875, p. 580.

replacement of fluorine by hydroxyl. Accordingly tests were made for water and it has been found to be always present. This fact seems to have been generally overlooked.

In testing by the ordinary closed tube method it is not always evident that hydroxyl is present, since in a mineral like topaz an acid vapor comes off, probably hydrofluosilicic acid, instead of water. By mixing the mineral, however, with lime or some other substance to hold the fluorine, water is evolved. In order to determine to what extent hydroxyl is present and what part it plays in the chemical composition, material from a number of localities has been examined, and it will be shown in the course of this article that the variations which topaz shows both in chemical composition and physical properties result from an isomorphous replacement of fluorine by hydroxyl, while a simple composition has been established which can be expressed by the formula $[\text{Al}(\text{F}, \text{OH})]_2\text{SiO}_4$.

Method of analysis. — The important features of the analysis were of course the accurate determination of fluorine and water. For fluorine the method of Berzelius was adopted. The mineral mixed with half its weight of quartz, was fused with five times the total weight of mixed sodium and potassium carbonates. The fusion was soaked out, filtered and washed with hot water. To the hot filtrate five to ten grams of ammonium carbonate were added and after cooling, still another addition of the same reagent. After standing in the cold for twelve hours the precipitate was filtered off, the excess of ammonium carbonate expelled from the filtrate by heating in a platinum dish on the water bath, and an ammoniacal solution of zinc oxide added. After evaporating until the odor of ammonia had disappeared the zinc oxide precipitate was removed by filtration, the filtrate heated and dilute nitric acid added until the excess of alkali carbonate was nearly decomposed. To the slightly alkaline boiling solution an excess of calcium chloride was added and from this point the precipitate was treated as previously described by one of us.*

* Amer. Jour. Sci., 1894, vol. 47, p. 190.

That determinations made by this method are satisfactory was proved by the following: In an experiment with topaz the residue resulting from soaking out the alkali carbonate fusion, and the precipitates formed by the ammonium carbonate and zinc oxide were united, mixed with a fresh portion of alkali carbonates, fused and treated as before. The amount of fluorine that was obtained by this second treatment was only 0.07 per cent, showing that practically all may be extracted by one fusion. Moreover, fluorine determinations were made by the above method in an artificial mixture of cryolite, cyanite, and quartz, taken in proportions to correspond with the composition of topaz with the following results:

Cryolite taken.	Fluorine calculated.	Fluorine found.	Loss.
0.3325	0.1805	0.1788	0.0017

This result indicates only a slight deficiency, and it is probable that the determinations in the regular topaz analyses are not over 0.20 per cent low, as usually a gram and sometimes a gram and a half of the mineral were taken for a determination. In the above no allowance has been made for what might be recovered by a second fusion of the residues, and probably some of the loss is occasioned by volatilization during the alkali carbonate fusion, but since the crucible was kept covered this must have been very slight. Since water is present, it is evident that attempts that have been made to determine fluorine by loss on ignition, assuming that silicon fluoride is given off, cannot have given reliable results. For the determination of water, the mineral has been fused with dry sodium carbonate and the water absorbed in a weighed sulphuric acid tube. The method, which has been carefully tested, gives accurate results. The mineral is completely decomposed and it is impossible for acid vapors to pass off with the water. There can be no doubt about the water having come from hydroxyl, since it is not driven off except at an intense heat. In an experiment on topaz from Stoneham, Me., where the

water was found to be 0.98 per cent, the powder suffered a loss of only 0.12 per cent by heating for a long time in a platinum crucible at the highest heat of a ring burner.

The remainder of the analysis was conducted in the ordinary manner.

Material for analysis. — The specimens which we have examined are from the following localities:

Stoneham, Maine. — The material was colorless and transparent and was taken from the center of a large crystal in the Brush collection, catalogue number 185. Analyses have also been made by Genth* and Whitfield.† The former found 18.83 and the latter 17.10 per cent of fluorine, also Na_2O 1.25, K_2O 0.14 and H_2O 0.20 per cent. A careful test that we have made for alkalis has shown that they are absent.

Pike's Peak, Colorado. — A perfectly colorless and transparent cleavage piece from a large crystal.

Nathrop, Colorado. — Wine yellow crystals in rhyolite, described by Cross.‡ The habit is similar to figure 4, page 493 of the sixth edition of Dana's Mineralogy, or figure 54, page 123 of Hintze's Mineralogy.

Utah. — Perfectly colorless transparent crystals from the rhyolite of the Thomas Range, forty miles north of Sevier Lake. The crystals were selected from a suite of specimens in the Brush collection, and have been described by A. N. Alling.§

San Luis Potosi, Mexico. — Colorless, transparent crystals like those described by Bücking|| and similar to the ones from Nathrop.

Zacatecas, Mexico. — Colorless crystals similar to the preceding. The material was generously supplied to us by Prof. A. J. Moses, from the mineralogical collection of the Columbia School of Mines, New York.

* Trans. Am. Phil. Soc. Oct., 1885, p. 43.

† Amer. Jour. Sci., 1885, vol. 29, p. 378.

‡ Ibid., 1886, vol. 31, p. 443.

§ Ibid., 1887, vol. 33, p. 146.

|| Zeitschr. Kryst., xii, p. 424, 1886.

Schneckenstein, Saxony. — Wine yellow crystals, selected from a suite of specimens in the Brush collection.

Adun-Chalon, Siberia. — The specimen corresponded to the description given by Kokscharow.* A colorless and transparent crystal in the Brush collection was used for the analysis.

Tenagari, Mino, Japan. — The material was taken from a colorless, transparent crystal, in habit like those from Adun-Chalon.

Minas Geraes, Brazil. — Transparent, yellow crystals selected from a suite of specimens in the Brush collection.

We take pleasure in expressing to Mr. Geo. L. English of New York our thanks for generously supplying us with the specimens from Nathrop, San Luis Potosi and Japan.

The following complete analyses have been made :

Utah.

	I.	II.	Average.	Ratio.		Theory for [AlF] ₂ SiO ₄ .
SiO ₂	31.93	. . .	31.93	0.532	0.98	32.61
Al ₂ O ₃	56.26	. . .	56.26	0.551	1.015	55.44
F	20.33	20.41	20.37	1.093	2.02	20.65
H ₂ O	0.19	. . .	0.19 ÷ 9 = 0.021			
			108.75			108.70
O equivalent to F.			8.58			8.70
			100.17			100.00

Nathrop, Colorado.

			Ratio.	
SiO ₂	32.23		0.537	0.99
Al ₂ O ₃	56.01		0.550	1.01
F	20.42	1.075	1.107	2.03
H ₂ O	0.29 ÷ 9 = 0.032			
		108.95		
O equivalent to F.		8.60		
		100.35		

* Materialien zur Min. Russlands, II, p. 232.

<i>Japan.</i>					
	I.	II.	Average.	Ratio.	
SiO ₂	32.28	. . .	32.28	0.538	0.98
Al ₂ O ₃	56.61	. . .	56.61	0.555	1.02
F	19.41	19.60	19.50	1.027	} 1.090
H ₂ O	0.57	. . .	0.57 ÷ 9 = 0.063		
			108.96		
O equivalent to F.			8.21		
			100.75		

<i>Schneckenstein, Saxony.</i>					
				Ratio.	
SiO ₂	32.82			0.547	1.00
Al ₂ O ₃	55.41			0.543	1.00
F	18.50		0.974	} 1.077	} 1.97
H ₂ O	0.93 ÷ 9 = 0.103				
			107.66		
O equivalent to F.			7.80		
			99.86		

<i>Stoneham, Maine.</i>					
	I.	II.	Average.	Ratio.	
SiO ₂	32.28	32.40	32.34	0.539	0.99
Al ₂ O ₃	56.33	56.33	56.33	0.552	1.01
F	18.56	18.30	18.43	0.970	} 1.080
H ₂ O	1.04	0.93	0.98 ÷ 9 = 0.110		
			108.08		
O equivalent to F.			7.76		
			100.32		

<i>Brazil.</i>					
				Ratio.	
SiO ₂	32.53			0.542	1.00
Al ₂ O ₃	55.67			0.546	1.00
F	15.48		0.815	} 1.087	} 2.01
H ₂ O	2.45 ÷ 9 = 0.272				
			106.13		
O eq. to F.			6.52		
			99.61		

Theory for
[Al(F,OH)]₂SiO₄
F : OH = 9 : 1.

Theory where
F : OH = 3 : 1.

From the results of these analyses it is evident that fluorine has been replaced by hydroxyl, and the ratios indicate very clearly that $\text{SiO}_2 : \text{Al}_2\text{O}_3 : \text{F} + \text{OH} = 1 : 1 : 2$ as required by either of the following formulæ $[\text{Al}(\text{F}, \text{OH})_2]\text{SiO}_4$ or $[\text{Al}(\text{F}, \text{OH})_2]\text{AlSiO}_4$. The first two analyses show very little hydroxyl, so that the material may be regarded as practically the pure fluorine compound, $[\text{AlF}]_2\text{SiO}_4$. In addition to the complete analyses, isolated determinations have been made on material from the other localities mentioned on pages 234 and 235, and these results will be given beyond in tabular form.

Physical properties and their relations to the chemical composition. — The specific gravities were very carefully determined on a chemical balance, pains being taken to boil the crystals for some time in water to expel any air bubbles. The results vary within the limits 3.574 and 3.533, a difference of only 0.041, and as a rule they decrease as the molecularly lighter hydroxyl replaces fluorine.

Also basal plates were prepared and the divergence of the optical axes 2E measured on a large axial angle apparatus. The values for 2E have been found to vary in topaz from different localities and according to the observations of Des Cloizeaux they extend from $129^\circ 30'$ on crystals from Durango, Mexico* to $71^\circ 32'$ on those from Mugla, in Natolien, Asia Minor,† both measurements being for red. These variations have generally been supposed to be connected with some change in chemical composition, but a satisfactory explanation has never been given. In the following table the measurements that we have made are arranged according to decreasing values of 2E for yellow, and with these the determinations of the specific gravity, fluorine and water are given :

	2E yellow.	Specific gravity.	Fluorine.	Water.
Zacatecas, Mexico,	$126^\circ 28'$	3.574	. . .	0.18
Thomas Range, Utah,	$125^\circ 53'$	3.565	20.37	0.19
Nathrop, Colorado,	$125^\circ 51'$	3.567	20.42	0.29
Pike's Peak, Colorado,	$122^\circ 42'$	3.567	. . .	0.48

* Bull. Soc. Min. de France, ix, p. 135, 1886.

† Nouv. rech., Inst. France, xviii, p. 612.

	2E yellow.	Specific gravity.	Fluorine.	Water.
Tenagari, Japan,	120° 59'	3.565	19.50	0.57
Adun-Chalon, Siberia,	118° 46'	3.562	19.24	0.58
San Luis, Mexico,	118° 17'	3.575	19.53	0.80
Schneckenstein, Saxony,	114° 28'	3.555	18.50	0.93
Stoneham, Maine,	113° 50'	3.560	18.56	0.98
Minas Geraes, Brazil,	84° 28'	3.532	15.48	2.45
“ “ “		3.523	. . .	2.50

On the last mentioned crystal the value of 2E was not measured owing to the strong optical anomalies which the section presented; it was observed, however, that the angle was small. It is evident from the results given in the table that the value of 2E decreases as the percentage of water increases or as fluorine is replaced by hydroxyl, and this relation is so constant that the percentage of water can be told from the value of 2E. It is evident, therefore, that the topaz from Durango, mentioned by DesCloizeaux as giving the largest value of 2E (129° 30') must be the nearest approach to the fluorine compound, while that from Asia Minor, also cited by him as giving the smallest value of 2E (71° 32') must be the richest in water or hydroxyl and poorest in fluorine of any topaz that has thus far been examined.

The indices of refraction also show a progressive change along with the variations of 2E as may be seen by the following determinations, given for yellow light by different investigators.

	2E.	2V.	α .	β .	γ .
Thomas Range, Utah,*	123° 24'	67° 18'	1.6072	1.6104	1.6176
Nerchinsk, Adun-Chalon Mts.,†	121° 55'	65° 30½'	1.61327	1.61597	1.62252
Colorless Crystal, Brazil,‡	120° 40'	65° 14'	1.6120	1.6150	1.6224
Schneckenstein, Saxony,†	114° 17'	62° 33'	1.61549	1.61809	1.62500
“ “ §	110° 12'	60° 55'	1.6156	1.6180	1.6250
Minas Geraes, Brazil,†	86° 21'	49° 37'	1.62036	1.63077	1.63747

* Alling. Amer. Jour. Sci., 1887, vol. 33, p. 146.

† Mülheims. Zeitschr. Kryst., xiv, p. 226, 1888.

‡ Des Cloizeaux. Manuel de Minéralogie, p. 475, 1862.

§ Zimányi. Zeitschr. Kryst., xxii, p. 339, 1893.

As hydroxyl replaces fluorine, therefore, the indices of refraction increase and the strength of the double refraction decreases, as shown by the values $\gamma - a$ in the extremes:

Thomas Range, Utah $\gamma - a = 0.0104$

Minas Geraes, Brazil $\gamma - a = 0.00811$

The crystallographic axes are also affected by the isomorphous replacement of fluorine by hydroxyl. The variation however is not very great and only exact determinations can be used for showing it. Mr. C. A. Ingersoll has kindly made for us some careful measurements on a crystal from the Thomas Range, Utah, which, next to the topaz from Zacatecas, contains the least water of any examined by us, and upon which the forms o (221) and f , (021) were well developed and gave beautiful reflections. Also on one from Brazil upon which very exact measurements could be obtained from the f (021) faces only, the other forms, the striated prism and the pyramid u , (111) not being suitable for measurement.

Utah.

Measured.	Measured.	Calculated.
$f \wedge f, 021 \wedge 0\bar{2}1 = 87^\circ 19'$	$o \wedge o, 221 \wedge \bar{2}21 = 105^\circ 10'$	$105^\circ 10'$
$o \wedge o, 221 \wedge \bar{2}21 = 49^\circ 36'$	$o \wedge o, 221 \wedge \bar{2}21 = 127^\circ 47'$	$127^\circ 51'$

Brazil.

$$f \wedge f, 021 \wedge 0\bar{2}1 = 86^\circ 55\frac{1}{2}'$$

The axial ratios are given in the following table and with them a number of others given by investigators who regard them as very exact.

	a	b	c
Utah, Ingersoll	0.528110	1	0.477115
Urals, Koksharov *	0.528542	1	0.476976
Schneckenstein, Laspeyres †	0.531548	1	0.475973
Brazil, Ingersoll		1	0.473862

Optical anomalies.—Of the crystals examined by us the only ones that showed optical anomalies were those from

* Materialien zur Min. Russ., ii, p. 198, 1854.

† Zeitschr. Kryst., i, p. 351, 1877.

Brazil. A basal section of the crystal that was used for the complete analysis showed an interior rhomb, having the outline of the unit prism, surrounded by four symmetrical trapeziums, and two opposite V-shaped segments, with their angles turned toward and touching the acute angles of the inner rhomb. The disposition of the parts was practically like that described by Mallard* and Mack.† The extinction directions of the outer segments corresponded almost exactly to that of the inner rhomb. On another crystal from Brazil, for which only the specific gravity and water determinations are given, the optical anomalies were much more marked, and the extinction in the different segments undulatory, so that the divergence of the optical axes $2E$ could not be measured. When the sections were examined by transmitted light it was evident that they were not homogeneous, since the well defined outlines between the inner rhomb and outer segments indicated a variation in the refractive indices. The structure indicates very clearly the existence of an inner core or older crystal, surrounded by a later growth of topaz of different composition. This idea agrees with the observations of Des Cloizeaux, who found that the central and outer segments of a zonal crystal gave different values for $2E$. Since it has been shown that the physical properties vary with the composition all the changes to which such a compound crystal is subjected must give rise to mechanical strains and cause the disturbance in the optical orientation of the different zones.

Comparison between topaz and herderite.—The changes that have been brought about by the partial substitution of fluorine by hydroxyl have previously been studied by one of us,‡ and it will be interesting in closing to make a comparison of the results that have been obtained. In herderite we know the pure hydroxyl compound, hydro-herderite, $\text{Ca}[\text{BeOH}]\text{PO}_4$, and the hydrofluor-herderite, $\text{Ca}[\text{Be}(\text{OH},\text{F})]\text{PO}_4$, with $\text{OH} : \text{F} = 3 : 2$. With topaz the nearly pure

* Ann. Mines, x, p. 155, 1876.

† Wied. Ann., xxviii, p. 153, 1886.

‡ Amer. Jour. Sci., 1894, vol. 47, p. 329.

fluorine extreme is known, $[\text{AlF}]_2\text{SiO}_4$, and the hydrofluor-topaz from Brazil, $[\text{Al}(\text{F},\text{OH})]_2\text{SiO}_4$, with $\text{F} : \text{OH} = 3 : 1$.

In both herderite and topaz an increase in hydroxyl is accompanied by a decrease in specific gravity and an increase in the indices of refraction. In monoclinic herderite the axes of greatest and least elasticities correspond nearly to the crystallographic axes, and overlooking this slight deviation the optical orientation in both minerals is the same, $\mathfrak{a} = a$, $\mathfrak{b} = b$ and $\mathfrak{c} = c$. Since topaz is positive and herderite negative the acute bisectrices are $\mathfrak{c}$ and $\mathfrak{a}$ respectively, but the angle of the optical axes measured in each mineral over the axis of least elasticity (that is in herderite over the obtuse bisectrix) is smaller for the hydroxyl than for the fluorine compound. In both minerals the substitution of hydroxyl for fluorine causes a change in the lengths of the crystallographic axes but the changes are not of the same character, since in herderite the a and c axes both increase while with topaz a increases and c decreases.

ON CANFIELDITE, A NEW SULPHOSTANNATE OF SILVER, FROM BOLIVIA.

By S. L. PENFIELD.

(From Amer. Jour. Sci., 1894, vol. 47, pp. 451-454.)

IN the August number of the American Journal of Science, 1893, page 107 (page 198 of this volume) the author described as a new species a germanium mineral from Bolivia, to which the name canfieldite was given. It was shown that the mineral was identical with argyrodite in chemical composition, but differed apparently in crystallization, canfieldite being isometric while argyrodite was monoclinic, according to the description of Weisbach.* The discovery of the isometric mineral was communicated by letter to Professor Weisbach, and soon after the publication of the author's article a reply was received from him, in which it was stated that better crystals of the Freiberg argyrodite than those originally described had been examined, and the results had shown that they were isometric and tetrahedral. These conclusions have since been published.† The forms *m* and *o* of Weisbach‡ are regarded as the dodecahedron (110), *f* and *k* as the tetrahedron (111), and *v* as the negative pyramidal-tetrahedron (3 $\bar{1}$ 1). Argyrodite being isometric it is evident that the Bolivian mineral is not a new species and the name canfieldite is therefore withdrawn. For the sake of simplicity it is a satisfaction to have the Bolivian mineral identical with that from Freiberg, and it is regretted that the isometric character of argyrodite was not made known before the publication of the original canfieldite paper.

* Jahrb. f. Min., 1886, ii, p. 67.

† Jahrb. f. Min. 1894, i, p. 98.

‡ Compare figure in Dana's Mineralogy, sixth edition, p. 150.

There has also recently come into the author's possession, through the kindness of Mr. Wm. E. Hidden of New York, a specimen from La Paz, Bolivia, which was supposed to be argyrodite. Its total weight was a little over seven grams and it consisted of a few attached octahedrons, modified by dodecahedron planes, the largest crystal measuring 13 mm. in axial diameter. The only visible impurity was a very little metallic silver in wire form, deposited in a few places on the outside of the crystals. The mineral is almost identical with argyrodite in all of its physical properties. The luster is brilliant metallic. Color black with the same bluish to purplish tone observed on argyrodite. The fracture is irregular to small conchoidal. Very brittle. Hardness $2\frac{1}{2}$ —3, specific gravity 6.276, that of argyrodite from Bolivia being 6.266. Heated before the blowpipe on charcoal at the tip of the blue cone the mineral fuses at about 2 and yields a coating of the mixed oxides of tin and germanium. This is white to grayish near the assay, tinged on the outer edges with yellow. By continued heating a globule of silver results, but this is covered by a scale or coating of tin oxide. If the coating on the charcoal is scraped together and fused in the reducing flame with sodium carbonate, globules of tin are formed. In the closed tube sulphur is given off and at a high temperature a slight deposit of germanium sulphide, which fuses to globules, is formed near the assay. In the open tube sulphur dioxide is given off but no sublimate is deposited.

The following method was adopted for the analysis. The mineral was oxidized by concentrated nitric acid and the excess of the latter removed by evaporation. The residue after moistening with nitric acid was digested with boiling water for some time and the insoluble metastannic acid filtered off. This was transferred while still moist to a beaker and treated with strong ammonia into which hydrogen sulphide was conducted until the metastannic acid had gone into solution. A slight insoluble residue was filtered off at this point which contained about 0.10 per cent of tin and 0.40 per cent of silver. From the ammonium sulphide solution the tin was precipi-

tated by addition of a little sulphuric acid and weighed as oxide. The filtrate from the stannic sulphide was evaporated and yielded a little germanium which had not been separated from the tin by the nitric acid treatment. In the original filtrate from the metastannic acid, silver was precipitated by means of hydrochloric acid and weighed as chloride. The sulphur was next precipitated by barium nitrate, and after purifying by fusion with sodium carbonate weighed as barium sulphate. Before evaporating the filtrates hydrochloric acid and barium were removed by precipitation with silver nitrate and sulphuric acid. The excess of silver was finally removed by ammonium thiocyanate and the germanium obtained from the filtrate as described in a previous communication.* The results of the analysis are as follows:

		Ratio.		Theory for $\text{Ag}_3(\text{Sn,Ge})\text{S}_8$ where Sn : Ge = 12 : 5.
S	16.22	0.507	5.92	16.56
Sn	6.94	0.0589	} 0.0842	7.18
Ge	1.82	0.0253		1.83
Ag	74.10	0.686	8.00	74.43
Zn and Fe	0.21	. . .	. . .	. . .
	99.29			100.00

In this compound tin is undoubtedly isomorphous with germanium, and the two are present in about the proportion 12 : 5. The ratio of S : Sn+Ge : Ag in the analysis is very close to 6 : 1 : 8, indicating that the formula is $\text{Ag}_3(\text{Sn,Ge})\text{S}_8$ or $4\text{Ag}_2\text{S} \cdot (\text{Sn,Ge})\text{S}_2$. The agreement between the theory and the analysis is satisfactory.

The only sulphostannates thus far known to occur in nature are the rare species *stannite*, $\text{Cu}_2\text{S} \cdot \text{FeS} \cdot \text{SnS}_2$, *franckeite*, $5\text{PbS} \cdot \text{Sb}_2\text{S}_3 \cdot 2\text{SnS}_2$, *Cylindrite* (Kylindrit), $6\text{PbS} \cdot \text{Sb}_2\text{S}_3 \cdot 6\text{SnS}_2$, recently described by Frenzel,† and *plumbostannite*, a mineral of doubtful composition containing Pb, Fe, Sb, and S, described by Raimondi.‡ *Franckeite* has recently been described by Stelzner,§ and in it Winkler was able to identify

* Page 202.

† Zeitschr. Kryst., vi, p. 632, 1882.

† Jahrb. Min., 1893, II, p. 125.

§ Jahrb. Min., 1893, II, p. 114.

a small amount of germanium, probably about 0.10 per cent. These authors call attention to the fact that since tin and germanium belong to the same chemical group they are isomorphous with one another and suggest the probability of finding in Bolivia a sulphostannate of silver isomorphous with argyrodite. The new mineral described in this article corresponds precisely to this idea. As the Freiberg argyrodite has been shown to be isometric, and the name *canfieldite* cannot therefore be applied to the germanium compound, it is proposed now to transfer the name to the new isomorphous tin compound. It is not probable that this will cause confusion as the name as at first applied was not long in use and has never been introduced into any of the text-books or systems of mineralogy, and especially as it is now transferred to a species which is very closely related, and should come next to argyrodite in a natural system of classification. It is probable that various mixtures of argyrodite Ag_3GeS_6 and the molecule Ag_3SnS_6 will be found and it would seem best to consider this latter as the canfieldite molecule, while the intermediate isomorphous mixtures would be called argyrodite or canfieldite, according as the germanium or the tin molecule predominated.

Regarding the crystallization of the argyrodite and canfieldite from Bolivia the specimens examined by the author are apparently holohedral. The octahedron faces are equally developed and have the same luster. There is, however, on each of the dodecahedral faces of the canfieldite specimen a distinct furrow or slight depression running in the direction of the longest diagonal. This may indicate a twinning which has given rise to the apparently holohedral form, or the latter may of course have resulted from an equal development of positive and negative tetrahedrons.

ON THE OCCURRENCE OF THAUMASITE AT WEST PATERSON, NEW JERSEY.

By S. L. PENFIELD AND J. H. PRATT.

(From Amer. Jour. Sci., 1896, vol. i, pp. 229-233.)

IN 1878 Baron von Nordenskiöld* described a mineral from the copper mines of Åreskuta, Jemtland, Sweden, which, according to the analyses of Lindström,† had the composition $\text{CaSiO}_3 \cdot \text{CaCO}_3 \cdot \text{CaSO}_4 \cdot 14\text{H}_2\text{O}$ and to which the name thaumasite was given, from *θαυμάζειν*, to be surprised. The mineral was not found in distinct crystals but was crystalline, and on a fracture showed a fine fibrous structure. Its homogenous character and its right to be considered a distinct mineral species rested upon the following: The material seemed to be homogeneous when examined with the microscope, and the three analyses of Lindström, made upon material collected in the early part of this century by Polheimer, in 1859 by Nordenskiöld, and in 1878 by Engberg, agreed not only very closely with one another but also with the theory demanded by the formula.

That a mineral with such a remarkable composition was capable of existence was not accepted by all mineralogists, and Bertrand,‡ on examining thin sections of it with the microscope, was led to believe that it was a mixture, composed of a uniaxal mineral with negative double refraction supposed to be calcite, of a biaxial mineral gypsum, and of a third mineral, the optical properties of which could not be made out, probably calcium silicate or wollastonite.

The idea of Bertrand's that thaumasite was a mixture was not accepted by Nordenskiöld, and the latter to sustain his

* Comptes rendus, vol. lxxxvii, p. 313, 1878.

† Ofv. Ak. Stockholm, vol. xxxv, No. 9, p. 43, 1878.

‡ Bull. Soc. Min. de France, vol. iii, p. 159, 1880, and vol. iv, p. 8, 1881.

position presented the following arguments,* which were very convincing: First, if it were possibly a mixture it certainly would be very remarkable that three independent samples, collected at such widely separated periods, should agree so closely in percentage composition. Second, there is no known hydrated calcium silicate which, when mixed with calcite and gypsum, could yield a product containing over 42 per cent of water. Third, it would not be possible for a mixture of calcite, gypsum and wollastonite, with specific gravities of 2.72, 2.31, and 2.90 respectively, to yield a product with such a low specific gravity as thaumasite, 1.877.

Specimens were moreover sent to Lacroix for renewed optical examination, and in a letter to Nordenskiöld he states† that the material was found to be practically homogeneous, uniaxial and with negative double refraction, but whether hexagonal or tetragonal could not be determined. The uniaxial material which Bertrand had taken for calcite was in reality thaumasite, and Bertrand in a letter to Nordenskiöld‡ withdrew his objection. He gives also the approximate indices of refraction $\omega = 1.503$, $\epsilon = 1.467$, which differ from those of calcite.

In 1890 Widman§ described specimens of thaumasite belonging to the mineral collection of the University of Upsala, which are reported to have been found at Kjölland, about thirteen miles from the original locality Åreskuta, and two analyses by Hedström quoted by him agree very closely with the ones made by Lindström. From Hedström's analyses the formula $\text{CaSiO}_3 \cdot \text{CaCO}_3 \cdot \text{CaSO}_4 \cdot 15\text{H}_2\text{O}$ was derived, and as pointed out by Widman this slight change in the formula agrees satisfactorily with the analytical results of Lindström, who really had found over fourteen and one-half molecules of water.

It is with pleasure that the authors are able to announce the discovery of this unusually interesting mineral at Burger's

* Geol. För. Förehandl., Stockholm, vol. v, p. 270, 1880.

† Geol. För. Förehandl., Stockholm, vol. ix, p. 35, 1887.

‡ Ibid., vol. ix, p. 131, 1887.

§ Ibid., vol. xii, p. 20, 1890.

quarry, West Paterson, New Jersey, the material having been first brought to our notice by Mr. Geo. L. English, of New York, who sent a specimen of it to the mineralogical laboratory of the Sheffield Scientific School for identification. The mineral occurs as an aggregate of prismatic crystals, sometimes so loosely held together that the individuals can be separated by crushing between the fingers, while more often the masses are firm and have somewhat the appearance of white alabaster. Occasionally distinct prismatic crystals were observed, averaging 0.5 mm. in diameter and 2 to 4 mm. in length, but they were poorly formed and without distinct terminations. Some of the masses showing fine prismatic crystals have a decidedly silky luster. There is a distinct prismatic cleavage. Measurements were only possible in the prismatic zone and approximated to 60° , which determine the crystallization as hexagonal. On examining fragments imbedded in Canada balsam ones can readily be found which show a uniaxial interference figure with negative double refraction. Using a polished plate, the index of refraction for the ordinary ray was determined by means of total reflection in α -mono-bromnaphthalene and found to be 1.5125 for yellow, Na. By means of a prism of $32^\circ 58'$ the following values were also obtained for yellow, $\omega = 1.519$ and $\epsilon = 1.476$. It must be stated, however, that a prism cut from a crystalline aggregate cannot yield wholly satisfactory results, as the light does not traverse a single individual, and that for example which yielded the extraordinary value above was vibrating in crystals whose vertical axes were approximately and not perfectly parallel to the edge of the prism. Levy and Lacroix* give $\omega = 1.507$ and $\epsilon = 1.468$.

In order to be absolutely sure of the uniform character of the material for analysis, selected pieces of the mineral were crushed and sifted to a uniform grain and separated by means of methyl iodide, CH_3I , which was diluted with ether. That every particle of the mineral in the separator floated at a specific gravity of 1.887 and sank at 1.875, a difference of only

* Les Minéraux des Roches, p. 286, 1888.

0.012, is sufficient proof of the homogeneous character and great purity of the material. Lindström gives as the specific gravity of the Swedish mineral 1.877 and Widman gives 1.83.

The results of the analysis are as follows:

	I.	II.	III.	Average.	Ratio.	
SiO ₂	9.23	9.33	9.23	9.26	0.155	0.97
CO ₂	6.87	6.77	. . .	6.82	0.155	0.97
SO ₃	13.56	13.32	. . .	13.44	0.168	1.05
CaO	. . .	27.08	27.19	27.13	0.484	3.04
H ₂ O	42.81	42.72	. . .	42.77	2.377	15.00
Na ₂ O	0.39	. . .	. . .	0.39	. . .	. . .
K ₂ O	0.18	. . .	. . .	0.18	. . .	. . .
				99.99		

The ratio of SiO₂: CO₂: SO₃: CaO: H₂O is very nearly 1:1:1:3:15, demanded by the formula CaSiO₃ . CaCO₃ . CaSO₄ . 15H₂O. The analytical results are, moreover, very close to those obtained upon the Swedish mineral by Lindström and Hedström. A slight amount of alkali sulphate is probably present as impurity, therefore the alkalies have been neglected in making the above calculation. That Na₂O and K₂O are not isomorphous with CaO is shown by the following experiment: 1.1765 grams of the powdered mineral were treated in a platinum dish for over two days with cold water, the insoluble mineral was then filtered off and the soluble portion analyzed, with the following results: SiO₂, 0.39 per cent; SO₃, 0.56; CaO, 0.56; Na₂O + K₂O, 0.25. These indicate that thaumasite is slightly soluble and that the alkalies have an independent existence, for a quantity of Na₂O + K₂O equal to about one-half of that found in the original analysis was extracted, while relatively only a very small proportion of the calcium was dissolved, a result which would not have taken place if the alkalies had belonged with the thaumasite. A small quantity of alkali sulphate may, therefore, be regarded as impurity, and deducting from the analysis the alkalies and sufficient SO₃ (0.64 per cent) to convert them into sulphates, and recalculating to one hundred per cent, the following results

are obtained, which agree satisfactorily with the values required by theory :

	By recalculation.	Theory.
SiO ₂	9.38	9.64
CO ₂	6.90	7.08
SO ₃	12.95	12.86
CaO	27.47	27.01
H ₂ O	<u>43.30</u>	<u>43.41</u>
	100.00	100.00

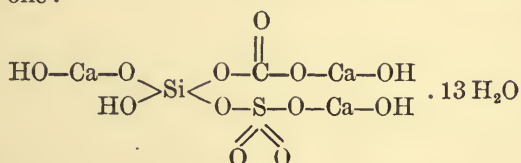
Hoping to obtain data concerning the constitution of the mineral, experiments were made to determine the temperature at which the water was driven off. As determined by Lindström, the mineral slowly loses water at 100° C., and in our experiment, after heating for over ninety hours, a loss of 29.35 per cent was obtained, but the weight had not become constant. At 150° the weight soon became constant and then at 200°, 250° and 300°, respectively, constant weights were obtained, and in each case the heating was continued until the loss of weight during several hours did not amount to more than a few tenths of a milligram. Between 300° and 360° no loss of weight was obtained, but the material still contained water which, as seen by a closed tube experiment, was expelled at much below a red heat.

The results obtained from 0.6663 gram of the air-dry mineral are as follows :

	Loss.	Proportional parts using $\frac{1}{18}$ of total H ₂ O as unity.
Two days in desiccator	Nothing	
Nine hours at 150°	37.41	13.13
Seven hours at 200°	1.82	0.64
Eight hours at 250°	1.41	0.50
Five hours at 300°	1.05	0.37
Below redness	<u>1.08</u>	<u>0.38</u>
Total	42.77	

It is evident from the above that 13 molecules are to be regarded as water of crystallization and two molecules, sufficient

to form four hydroxyls, as constitutional. The last two molecules are, moreover, expelled at four separate temperatures, indicating the existence of four hydroxyls which play different parts or have different positions in the molecular structure. It is evident also that the CaSiO_3 , CaCO_3 , and CaSO_4 , together with the water, are united in some way into a complex molecule, and probably as suggested by Groth * in some way analogous to the combination of silicate and sulphate in the haiyne-nosean group of minerals or of silicate and carbonate in cancrinite. Regarding silica as the linking non-metallic element, the following constitution may be suggested as a possible one :



The above may also be expressed as $[(\text{CaOH})\text{CO}_2] [(\text{CaOH})\text{SO}_3] [\text{CaOH}] \text{HSiO}_4 \cdot 13\text{H}_2\text{O}$. The formula agrees in a very satisfactory manner with the results obtained by driving out the water, for it demands four independent and different hydroxyl molecules. Formulæ may also be written with four hydroxyls and with either carbon or sulphur as the linking element, but they do not seem to the authors so probable as the one given above.

The occurrence of thaumasite at Paterson is in the trap which has been quarried for road material. It is associated with heulandite, apophyllite, laumontite, pectolite, chabazite, scolecite and natrolite, all of which are found at the locality in beautiful crystals. Widman mentions the occurrence of apophyllite with the thaumasite at Kjölland. The thaumasite has crystallized later than the zeolites and occurs upon or surrounding them. A considerable quantity of it was found.

In closing, the authors desire to express their thanks to Messrs. Geo. L. English & Co. of New York for generously furnishing them with material for the investigation.

* Tabellarische Uebersicht der Mineralien, p. 149, 1889.

ON PEARCEITE, A SULPHARSENITE OF SILVER.

By S. L. PENFIELD.*

(From Amer. Jour. Sci., 1896, vol. 2, pp. 17-29.)

THE mineral to be described as pearceite in the present article is a sulpharsenite of silver, Ag_9AsS_6 or $9\text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3$, analogous to polybasite Ag_9SbS_6 , and like the latter characterized by having a part of the silver replaced by copper and often by small quantities of zinc and iron. It cannot be claimed to be strictly a *new mineral*, for as an arsenical variety of polybasite it has previously been recognized, although no special name has been assigned to it. H. Rose† first described polybasite and gave the name to the species in 1828, and in 1833 he published‡ an analysis of a specimen from Schemnitz containing arsenic, with only a trace of antimony, while in the original polybasite from Durango, Mexico, described by him, both antimony and arsenic were present, and he recognized the fact that these elements were isomorphous and could mutually replace one another. The polybasites from Durango in Mexico, Freiberg in Saxony, Příbram in Bohemia, the Two Sisters' mine near Georgetown, the Yankee Boy mine near Ouray, and the Sheridan mine near Telluride in Colorado, the Comstock Lode in Nevada, and apparently from most localities, are essentially the antimony variety, and in mineralogical literature the composition of polybasite is usually given as a *sulphantimonite* of silver. Rammelsberg§ gives an analysis by Joy of polybasite from Cornwall, England, where antimony and arsenic are present in about equal molecular proportions, and the author in connection with Mr. Stanley H. Pearce, has published|| analyses of arsenical

* A portion of this paper treating of the *Crystallization of Polybasite* is here omitted. — EDITOR.

† Pogg. Ann., xv, p. 573, 1829.

‡ Loc. cit., xxviii, p. 56, 1833.

§ Mineralchemie, p. 102, 1860.

|| Amer. Jour. Sci., 1892, vol. 44, p. 15.

polybasite (*pearceite*) from the Mollie Gibson mine, Aspen, Colorado. This latter material was not distinctly crystallized, but was found in great quantity and was the mineral which carried the bulk of the silver in the most productive silver mine in Colorado at that time.

The author's attention has recently been called to the occurrence of beautifully crystallized pearceite, or arsenical polybasite from the Drumlummon mine, Marysville, Lewis and Clarke Co., Montana. The mineral was first sent by Mr. R. F. Bayliss, of the Montana Mining Co., to Dr. Richard Pearce, of Denver, with the request that it should be investigated, and the following analysis was made by Mr. F. C. Knight under Dr. Pearce's immediate supervision.

	Found.	Ratio.	Theoretical composition where Ag ₂ : Cu ₂ : Fe = 255: 143: 19.
S	17.71 ÷ 32 = 0.553	11.95	17.96
As	7.39 ÷ 75 = 0.098	2.11	7.02
Ag	55.17 ÷ 216 = 0.255	0.417 9.00	55.61
Cu	18.11 ÷ 127 = 0.143		18.34
Fe	1.05 ÷ 56 = 0.019		1.07
Insol.	0.42		. . .
	<u>99.85</u>		<u>100.00</u>

Dr. Pearce recognized that the mineral belonged to the polybasite class, where arsenic played the rôle usually taken by antimony, and forwarded the specimens, together with the analysis, to the author for an expression of opinion. As may be seen from the ratio, the proportion of S: As: (Ag₂ + Cu₂ + Fe) is very nearly 12: 2: 9, which is that demanded by the polybasite formula, and taking the metals in the same proportion as they are found in the analysis, Ag₂: Cu₂: Fe = 255: 143: 19, and calculating the theoretical composition, results agreeing very satisfactorily with the analysis are obtained.

Although recognizing that antimony and arsenic are isomorphous and may mutually replace one another, it is customary and has been found convenient in mineralogy to consider the sulphantimonites and sulpharsenites as distinct species, and to designate them by different names, and the author proposes

that hereafter the name polybasite shall be restricted to the antimony compound Ag_3SbS_6 , and to make of the corresponding arsenic compound, Ag_3AsS_6 , a distinct species. For the arsenical mineral he takes pleasure in proposing the name *pearceite* as a compliment to his friend, Dr. Richard Pearce, of Denver, whose keen interest in mineralogy and connection with one of the large smelting and refining works of Colorado have made him known alike to scientific men and to those interested in the development of the mining industries of the Rocky Mountain region. The author furthermore takes pleasure in expressing his thanks to Mr. Bayliss, who has taken a great interest in the investigation and naming of the mineral, and has most generously placed at his disposal all of the available material.

It seems best to give at this point the analyses of pearceite, already referred to, which have previously been published as arsenical varieties of polybasite. In the theoretical composition given with each the ratio of the metals is the same as in the accompanying analysis.

- I. H. Rose, $\text{Ag}_2 : \text{Cu}_2 : \text{Zn} : \text{Fe} = 335 : 24 : 9 : 6$.
 II. Penfield, after deducting 12.81 per cent of impurities, mostly PbS , $\text{Ag}_2 : \text{Cu}_2 : \text{Zn} = 263 : 117 : 43$.
 III. S. H. Pearce, after deducting 28.18 per cent of impurities, mostly PbS , $\text{Ag}_2 : \text{Cu}_2 : \text{Zn} = 276 : 102 : 49$.

	I.		II.		III.		Theory for Ag_3AsS_6
	Schemnitz.	Theory.	Aspen, Colo.	Theory.	Aspen.	Theory.	
S	16.83	16.19	18.13	18.13	17.73	18.02	15.50
As	6.23	6.32	7.01	7.08	6.29	7.03	6.05
Sb	0.25	...	0.30	...	0.18	...	...
Ag	72.43	73.47	56.90	57.07	59.73	59.06	78.45
Cu	3.04	3.08	14.85	14.91	12.91	12.77	...
Zn	0.59	0.60	2.81	2.81	3.16	3.12	...
Fe	0.33	0.34	...	...	...	...	...
	99.70	100.00	100.00	100.00	100.00	100.00	100.00

Crystallization.

The crystallization of pearceite is *monoclinic* but with a close approximation to rhombohedral symmetry. The habit is commonly hexagonal with the basal planes prominent and the zones of bevelling forms between them often highly modified. The material from which crystallographic data could be obtained came wholly from a single specimen where the crystals were implanted upon a gangue of quartz and imbedded in calcite, and were obtained by dissolving the latter in dilute acid. Unfortunately the crystals had grown close together, thus interfering more or less with another, and they also were cracked, probably owing to the severe shocks received in the processes of blasting and mining; consequently when liberated by dissolving the calcite they fell to pieces, so that usually only parts of crystals were available for measurement. The faces had a beautiful metallic luster, and when free from striations and vicinal planes gave excellent reflections on the goniometer. The determination of the crystalline form and the axial ratio proved to be a difficult matter owing to the fragmentary character of the crystals, their grouping, often in nearly parallel position, a probable twinning, and their close approximation to rhombohedral symmetry, and it was not until many measurements had been made upon a series of crystals that a satisfactory solution of the problem was obtained.

As fundamental measurements, the following were selected:

$$m \wedge m, 110 \wedge \bar{1}10 = 60^\circ 2'$$

$$c \wedge d, 001 \wedge 102 = 25^\circ 3'$$

$$c \wedge a, 001 \wedge 100 = 89^\circ 51'$$

from which the axial ratio was calculated:

$$a : b : c = 1.7309 : 1 : 1.6199;$$

$$\beta = 001 \wedge 100 = 89^\circ 51'$$

The crystals are quite highly modified, and it seems best before giving a list of the forms to explain the different kinds which were observed and to state something concerning their

occurrence. The basal pinacoid c (001) is prominent, is hexagonal or triangular in shape, and is characterized by triangular markings and vicinal planes, Figure 1, so that it was often impossible to obtain accurate measurements from it. The prism m (110) and the pinacoid a (100) are nearly at right angles to c and 60° from one another, so that the combination approaches very closely to a hexagonal prism, and it is sometimes impossible to distinguish a from m , or, without accurate measurements, to decide whether the forms between c and a or c and m modify the acute or obtuse angles. It is very probable that a twinning is present, similar to that of the micas and chlorites, where the twinning plane is at right angles to c in the zone $m \wedge c$, and where the parts are superimposed upon one another with c as the composition face, but no absolute proof of this was obtained. The crystals are opaque, so that optical tests could not be applied as was done by Miers,* who has described this kind of twinning on polybasite. If the twinning occurs on pearceite, as it probably does, it must cause uncertainty as to the identification of some of the forms in the zones between c and a and c and m , and it may also account in part for the decidedly rhombohedral aspect of many of the crystals. As far as could be observed, similar faces are often developed about equally above and below m and a in the zones between the basal planes, but to what extent this is due to twinning it is impossible to state. The faces in these zones are moreover commonly striated parallel to their mutual intersection, and while r and p , r° and p° , n and t and n° and t° (compare Figure 1 and the list of forms beyond), are the most prominent, other faces, especially e and e° , f and f° , s and s° and u and u° , are very often present. When q was observed it was always a prominent, dull face, not sharing in the horizontal striations of the other faces of the zone. It was only occasionally that forms were observed between c (001) and l ($\bar{3}10$) and they were always small, while the corresponding forms were not observed between (001) and ($\bar{3}10$). The pinacoid b (010) was identified, not only by the symmetrical arrangement of

* Min. Mag., viii, p. 204, 1889.

the forms with reference to it, but also by the similarity of the angles measured from it on to similar adjacent forms. The prism l (310) is often developed about equal in size to b , and with the latter would correspond in rhombohedral symmetry to a hexagonal prism of the second order. The prism h (130) and the clino-dome k (021) were found together on only one crystal as small faces symmetrically located with reference to the pinacoid b .

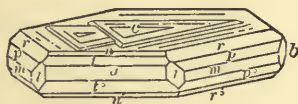


FIGURE 1.

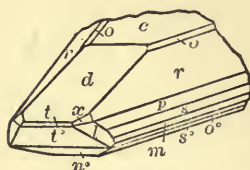


FIGURE 2.

Figure 1 shows the prevailing type of crystal, with hexagonal aspect, the characteristic triangular markings on the basal plane, but with only the most prominent of the beveling faces present. Two fragments were found which in habit were essentially like Figure 2. These had a decidedly monoclinic habit and were the most free from striations, vicinal faces and indications of a possible twinning of any crystals that were observed, and from them the fundamental measurements previously given were obtained.

A few crystals were quite remarkable for their size, the hexagonal plates being 3 cm. in diameter and 1 cm. thick, but they were coated with drusy quartz and could not be used for crystallographic measurement. The specimen showing the largest crystals was presented by Mr. Bayliss to the author for the Brush collection at New Haven. The crystals from which the measurements were obtained averaged less than 4 mm. in diameter.

The following list includes the forms which have been observed, but, as already stated, twinning may account for a similar form being found modifying both the acute and obtuse angles of the crystals and being repeated in the zones between c and a and c and m .

a , 100	d , 102	t° , 201	s , 221	s° , 221
b , 010	n , 101	e° , 401	u , 331	u° , 331
c , 001	t , 201	f° , 601	o° , 114	x , 311
l , 310	e , 401	o , 114	q° , 113	y , 313
m , 110	f , 601	r , 112	r° , 112	z , 3.1.12
h , 130	A , 203	p , 111	p° , 111	
k , 021	n° , 101	v , 332	v° , 332	

The forms corresponding to these, found by Miers* on polybasite, are c , m , n , t , p , s , r , and w (109).

The following table of measured angles includes a series which was selected wholly on account of the character of the reflections, due to the freedom of the faces from striations and other disturbing influences. They were mostly made on the two fragmentary crystals, already mentioned, having a habit like Figure 2, and where several measurements are given they

	Calculated.	Measured.	
$c \wedge a$, 001 $\wedge$ 100	89° 51'	89° 51' †	89° 49'
$c \wedge l$, 001 $\wedge$ 310	89° 52'	89° 48'	89° 54'
$c \wedge m$, 001 $\wedge$ 110	89° 55½'	89° 55'	
$m \wedge m$, 110 $\wedge$ 110	60° 2'	60° 2' †	
$b \wedge m$, 010 $\wedge$ 110	30° 1'	30° 1'	30° 1'
$a \wedge l$, 100 $\wedge$ 310	29° 59'	29° 58'	29° 57¼'
$b \wedge h$, 010 $\wedge$ 130	10° 54'	10° 53'	
$b \wedge k$, 010 $\wedge$ 021	17° 9'	17° 5'	
$c \wedge d$, 001 $\wedge$ 102	25° 3'	25° 3 †	25° 2½'
$c \wedge n$, 001 $\wedge$ 101	43° 2'	43° 4'	43° 5'
$c \wedge e^\circ$, 001 $\wedge$ 401	104° 49'	104° 53½'	
$c \wedge t^\circ$, 001 $\wedge$ 201	118° 00'	117° 56'	
$c \wedge n^\circ$, 001 $\wedge$ 101	136° 49½'	136° 52½'	
$c \wedge r$, 001 $\wedge$ 112	43° 3'	43° 3'	{ 43° 6' 43° 0'
$c \wedge p$, 001 $\wedge$ 111	61° 49'	61° 56'	
$d \wedge r$, 102 $\wedge$ 112	36° 14'	36° 12'	36° 16'
$b \wedge p$, 010 $\wedge$ 111	40° 15'	40° 12'	40° 12'
$b \wedge p^\circ$, 010 $\wedge$ 111	40° 10½'	40° 8'	
$b \wedge s$, 010 $\wedge$ 221	33° 12'	33° 12'	
$c \wedge y$, 001 $\wedge$ 313	47° 9'	47° 10'	47° 7'

* Loc. cit.

† Fundamental measurements.

represent independent ones in different zones or on different crystals. As may be seen, the measured angles show a fairly good agreement with the calculated values, and it may, therefore, be assumed that the axial ratio has been determined with a high degree of accuracy.

In the following table the calculated angles of most of the faces on to the basal plane are given, arranged so as to show the slight variation from one another and from rhombohedral symmetry of the forms d , o and o° ; Δ and q° ; n , r , n° and r° ; t , p , t° and p° ; v and v° ; e , s , e° and s° and f , u , f° and u° .

$c \wedge d = 25^\circ 3'$	$c \wedge n^\circ = 43^\circ 10\frac{1}{2}'$	$c \wedge v = 70^\circ 19'$	$c \wedge f = 79^\circ 45'$
$c \wedge o = 25^\circ 3'$	$c \wedge r^\circ = 43^\circ 7\frac{1}{2}'$	$c \wedge v^\circ = 70^\circ 27'$	$c \wedge u = 79^\circ 49\frac{1}{2}'$
$c \wedge o^\circ = 25^\circ 4\frac{1}{2}'$	$c \wedge t = 61^\circ 46\frac{1}{2}'$	$c \wedge e = 74^\circ 54'$	$c \wedge f^\circ = 80^\circ 2'$
$c \wedge \Delta = 32^\circ 0'$	$c \wedge p = 61^\circ 49'$	$c \wedge s = 75^\circ 00'$	$c \wedge u^\circ = 79^\circ 58'$
$c \wedge q^\circ = 31^\circ 58'$	$c \wedge t^\circ = 62^\circ 00'$	$c \wedge e^\circ = 75^\circ 11'$	$c \wedge z = 15^\circ 6\frac{1}{2}'$
$c \wedge n = 43^\circ 2'$	$c \wedge p^\circ = 61^\circ 56'$	$c \wedge s^\circ = 75^\circ 6'$	$c \wedge y = 47^\circ 9'$
$c \wedge r = 43^\circ 3'$			$c \wedge x = 72^\circ 44'$

Physical properties. — Pearceite is brittle, has an irregular to conchoidal fracture and no distinct cleavage. The hardness is about 3. The specific gravity was taken with a chemical balance on three different portions of carefully selected material and gave 6.125, 6.160 and 6.166, the mean of these being 6.15. The luster is metallic and the color of the mineral and the streak is black. The material, even in thin particles, is opaque. In the ruby silvers the arsenical compound proustite is more transparent than the antimony one pyrargyrite, and we might, therefore, naturally expect pearceite to be more transparent than polybasite, but that this is not the case may be due to the fact that the variety of pearceite under examination contains over 18 per cent of copper, while the published analyses of polybasite indicate usually about 5 and never over 10 per cent of this element.

Pyrognostics and other tests. — Before the blowpipe, pearceite decrepitates slightly and fuses at about one. Heated on charcoal in the oxidizing flame, a slight coating of As_2O_3 is formed and by addition of borax or sodium carbonate and con-

tinued heating a globule of metallic silver is obtained. In the open tube SO_2 is given off and a volatile sublimate of As_2O_3 is formed. In the closed tube the mineral fuses, yields a yellow sublimate of sulphide of arsenic and above the latter a very slight one of sulphur. The powder is readily oxidized and dissolved by nitric acid. The solution yields with hydrochloric acid an abundant precipitate of silver chloride and on addition of ammonia in excess the blue color characteristic of copper is obtained, while a slight precipitate of ferric hydroxide is formed.

Occurrence. — According to information received from Mr. Bayliss, the pearceite crystals were found with quartz and calcite lining a vug at only one place in the Drumlummon mine, and although a diligent search has been made for similar crystals in other parts of the mine none have been found. A few chalcopyrite crystals were observed intimately associated with the pearceite. High grade silver and gold ores are taken from the Drumlummon mine, and on one of the specimens of the ore argentiferous tetrahedrite, freibergite, was observed.

ON NORTHUPITE; PIRSSONITE, A NEW MINERAL;
GAY-LUSSITE AND HANKSITE FROM BORAX LAKE,
SAN BERNARDINO COUNTY, CALIFORNIA.

By J. H. PRATT.*

(From Amer. Jour. Sci., 1896, vol. 2, pp. 123-135.)

INTRODUCTION.

THE minerals to be described in this paper are from the remarkable locality of Borax Lake, San Bernardino County, California. They were brought to the author's notice, in the fall of 1895, by Mr. Warren M. Foote of Philadelphia, who sent one of them, the northupite, together with some of the associated minerals, to the mineralogical laboratory of the Sheffield Scientific School, for chemical investigation. About the same time Mr. C. H. Northup of San José, Cal., sent some minerals from the same region to Prof. S. L. Penfield. Among them, gay-lussite, hanksite and a third mineral, which has proved to be a new species, were identified. These same minerals were also observed among the specimens sent by Mr. Foote. Mr. Northup, in his letter of transmittal, stated that he had carefully saved all the crystals of the new mineral, having observed that they were different from gay-lussite in habit, and that he believed they would prove to be a new and interesting species.

Both Mr. Northup and Mr. Foote have thus most generously furnished material for this investigation, and the former has also supplied valuable information concerning the locality and mode of occurrence of the minerals. The author, therefore, takes great pleasure in expressing his thanks to both of these gentlemen for the services they have rendered.

* The tables of measured and calculated angles and also the part of this paper referring to gay-lussite are here omitted. — EDITOR.

In addition to the investigation of northupite and the new mineral, some interesting data concerning hanksite and gaylussite have also been obtained.

Occurrence.—The Borax Lake region has already been described by De Groot* and Hanks† and therefore only a brief description is necessary in this article.

This alkali lake, or better, alkali marsh, is situated in the northwestern corner of San Bernardino County near the Inyo County line and is 72 miles from Mojave, the shipping point for that district. Borax Lake proper is a small basin about one mile and a half in length by half a mile wide, separated by a narrow ridge from a larger basin, which is about ten miles long and five miles wide, known as "Dry Lake," "Alkali Flat," "Salt Bed," and "Borax Marsh." The appropriateness of these names is very apparent, for the marsh is really a dry lake, partly filled up with salt, borax, alkali, mud, and volcanic sand. During the wet seasons a little water accumulates, but it remains only a short time and is never over a foot or two deep, while in most places it is not more than two or three inches. In the smaller basin, however, the water stands considerably longer. The larger basin is somewhat lower than the other, the narrow ridge referred to above preventing the waters of the smaller basin from flowing into it.

At the present time, borax is the only product manufactured from the minerals of the locality, and it is from the smaller basin and the narrow ridge that most of it is obtained. Tincal, or native borax, has been found in crystals to a depth of 450 feet, which is as deep as explorations with drills have penetrated. "Crude borax" is described by Mr. Northup as found on the surface of the higher parts of the lake, in a condition resembling burnt bone. Underlying this is a very hard, uneven deposit of different salts, which is generally not disturbed. The crude borax is collected only to a depth varying from two to eight inches, although the original thickness is much greater. In about four years, the efflorescence

* Report State Min. of Cal., 1890, p. 534.

† Amer. Jour. Sci., 1889, vol. 37, p. 63.

of borax forms again, the solution being drawn up by capillary attraction and leaving the bone-like deposit on evaporation. Most of the borax is obtained from this crude material, although some is obtained by the evaporation of the natural solution of borax in the lake water.

The minerals described beyond were found while exploring the underlying formations, and were obtained by Mr. Northup after carefully working over the tailings or débris from the borings.

The minerals associated with the borax at this region are, according to Hanks,* sulphur, gold, cerargyrite, embolite, halite, anhydrite, thenardite, celestite, glauberite, gypsum, calcite, dolomite, trona, gay-lussite, natron, hanksite, colemanite, tincal, soda niter and hydrosulphuric acid. To this list sulphohalite, northupite and the new mineral to be described in this paper must be added. Of the foregoing, colemanite,† hanksite,‡ and sulphohalite§ were first derived from this locality.

NORTHUPITE.

A preliminary description of this mineral has been given by Mr. Warren M. Foote.|| According to information received from Mr. Northup, it has been found in only one boring, known as the "New Well," and was probably formed in a stratum of clay, about 450 feet below the surface. With two exceptions, northupite has been observed only in detached crystals, Mr. Foote having in his possession a single specimen showing two octahedrons of northupite attached to a crystal of the new mineral, pirssonite, to be described beyond, and a similar specimen being in the Brush collection.

Physical properties. — The crystallization is isometric, the octahedron being the only form observed. The crystals vary

* Amer. Jour. Sci., 1889, vol. 37, p. 66.

† Bull. Cal. Acad., No. 2, Jan., 1885, and Zeitschr. Kryst., 10, p. 179, 1884.

‡ Amer. Jour. Sci., 1885, vol. 30, pp. 133 and 136; also, 1889, vol. 37, p. 63.

§ Ibid., 1888, vol. 36, p. 463. Also this volume, p. 343.

|| Proceedings of the Acad. of Nat. Sci. Phil., Sept. 1895. Also Am. Jour. Sci., 1895, vol. 50, p. 480.

in size from less than a millimeter to rarely a centimeter in diameter. There is no apparent cleavage, but the crystals, which are extremely brittle, break with a distinct conchoidal fracture. The luster on fractured surfaces is decidedly vitreous. The hardness is between 3.5 and 4. The specific gravity was obtained by floating the crystals in methylen iodide diluted with methyl iodide and was found to be 2.380. The pure material is colorless, but owing to impurities the color of the crystals, as stated by Foote, varies from dirty white, pale yellow and greenish-gray to dark brown. The impurities are probably clay or organic matter and Foote has called attention to their arrangement in directions parallel to the axial planes of the isometric system. No decomposition on exposure to the air has been observed.

Optical properties. — Fragments of the mineral, when examined in polarized light, were found to be isotropic. By means of a prism of $79^{\circ} 35'$ the following indices of refraction were determined :

$$n_r = 1.5117 \text{ Li.} \quad n_y = 1.5144 \text{ Na.} \quad n_{gr.} = 1.5180 \text{ Tl.}$$

Chemical composition. — A qualitative examination showed the presence of carbonic acid, chlorine, sodium, magnesium, and minute traces of sulphuric acid and water. Potassium was very carefully tested for, but not even a trace of it could be detected.

The results of the analyses are as follows :

	I.	II.	Average.	Ratio.	
CO ₂	35.21	35.02	35.12	0.798	2.01
Cl	14.10	. . .	14.10	0.397	1.00
SO ₃	0.08	0.08	0.08	. . .	. . .
MgO	15.96	16.20	16.08	0.402	1.01
Na ₂ O	36.99	. . .	36.99	0.597	1.50
H ₂ O	0.72	. . .	0.72	. . .	. . .
Insol.	0.25	0.19	0.22	. . .	. . .
			103.31		
O equivalent to Cl			3.16		
			106.47		

The ratio of the $\text{CO}_2 : \text{Cl} : \text{MgO} : \text{Na}_2\text{O}$ is almost exactly 2 : 1 : 1 : 1.5. Two-thirds of the sodium, if taken to form a molecule of Na_2CO_3 , would leave just enough to form with the chlorine a molecule of NaCl . This would then give as the formula, $\text{MgCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot \text{NaCl}$.

The percentage composition required by this formula is given below, together with the results of the analysis recalculated to 100 per cent, after deducting the slight amounts of water and insoluble material and converting a sufficient amount of the soda into metallic sodium to unite with the chlorine and form NaCl .

	Found.	Calculated for $\text{MgCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot \text{NaCl}$.
CO_2	35.43	35.41
MgO	16.22	16.09
Na_2O	24.90	24.96
Cl	14.23	14.28
Na	9.22	9.26
	100.00	100.00

Pyrognostics.—Before the blowpipe, the mineral fuses at 1, with frothing, due to escaping carbon dioxide, and yields a white or grayish white mass, which reacts alkaline with moistened turmeric paper. The flame is colored intensely yellow. In the closed tube, the mineral decrepitates violently, sometimes giving off a trace of water, derived probably from impurities held mechanically in the crystals. The crystals are easily soluble in cold dilute hydrochloric and nitric acids with effervescence. Cold water acts slowly on the mineral, but hot water decomposes it very rapidly with separation of magnesium carbonate.

Name.—The name, *northupite*, was given to this mineral by Mr. Foote as a compliment to Mr. Northup, whose very careful search has brought to light a number of interesting minerals from this locality.

PIRSSONITE, A NEW MINERAL.

As stated in the introduction, a new mineral was first observed by Mr. Northup among some crystals of gay-lussite,

which it somewhat resembles. It has been found very sparingly in only one boring, "New Well," which also furnished the northupite crystals. With the two exceptions mentioned under northupite, only detached crystals have been observed, and they were probably formed in the same part of the deposit which yielded the northupite. Unfortunately, pirssonite must be classed among the rare minerals; but it is hoped that, as explorations are carried on, it will be found in other parts of the deposit.

Crystalline form. — The mineral crystallizes in the orthorhombic system and is hemimorphic in its development. The hemimorphic axis has been taken as the vertical one, and the forms which have been observed are as follows:

b , 010	p , 111	e , 131
m , 110	p° , 11 $\bar{1}$	x , 311

The axial ratio, derived from the measurements marked by asterisks in the table beyond, is as follows:

$$a : b : c = 0.56615 : 1 : 0.3019$$

Although the forms are not numerous the crystals show a considerable variety in habit. Figures 1 and 2, drawn with

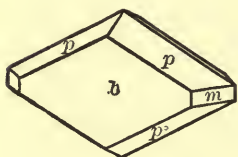


FIGURE 1.

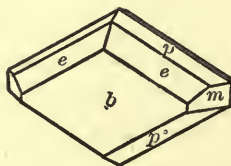


FIGURE 2.

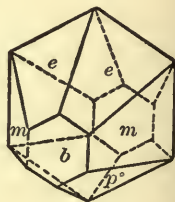


FIGURE 3.

010 in front, in order to show the shape better, represent the prevailing types. The pyramid e is developed at one extremity of the vertical axis only, and varies much in size. Often e alone terminates the upper end of the crystals, Figures 3 and 6. The pinacoid b is sometimes wanting as represented by Figures 4 and 5. The pyramid x was observed on only a

single fragmentary crystal and is not represented in the figures. The crystals vary much in size; the smaller ones, averaging about 5 mm. in greatest diameter, usually have the habit represented by Figures 1 and 2; while the larger ones, sometimes 15 mm. in length, are usually developed like Figures 4 and 5. The larger prismatic crystals are often only well terminated at that end where the *e* faces occur.

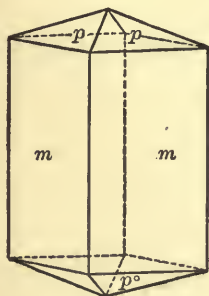


FIGURE 4.

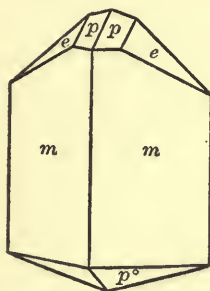


FIGURE 5.

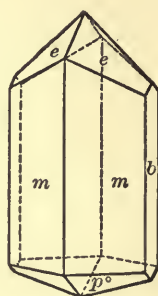


FIGURE 6.

The following table includes a list of the measured and calculated angles. As the reflections were not always very perfect, the extremes of two or more independent measurements are given:

		Measured.		Mean.	Calculated.
$p \wedge p''$	$111 \wedge \bar{1}\bar{1}1$	$62^\circ 57'$	$- 63^\circ 3'$	$*63^\circ 0'$	
$m \wedge m'''$	$110 \wedge 1\bar{1}0$	59°	$- 59^\circ 4' 30''$	$*59^\circ 2'$	
$p \wedge b$	$111 \wedge 010$	$74^\circ 51' 30''$	$- 75^\circ 7'$	$75^\circ 1' 33''$	$75^\circ 5'$
$p \wedge m$	$111 \wedge 110$	$58^\circ 32'$	$- 58^\circ 47'$	$58^\circ 38' 15''$	$58^\circ 30'$
$p \wedge p'$	$111 \wedge \bar{1}\bar{1}1$	$53^\circ 57'$	$- 54^\circ 5'$	$53^\circ 59' 36''$	$54^\circ 6'$
$p \wedge p'''$	$111 \wedge 111$	$29^\circ 54'$	$- 29^\circ 59' 30''$	$29^\circ 57' 30''$	$29^\circ 50'$
$b \wedge e$	$010 \wedge 131$	$51^\circ 14'$	$- 51^\circ 43'$	$51^\circ 26' 50''$	$51^\circ 22'$
$e \wedge e'''$	$131 \wedge \bar{1}\bar{3}1$	$76^\circ 56'$	$- 77^\circ 12'$	$77^\circ 4'$	$77^\circ 16'$
$x \wedge x'''$	$311 \wedge 3\bar{1}\bar{1}$	$18^\circ 12' 48''$		$18^\circ 12' 48''$	$18^\circ 10' 30''$
$x \wedge m$	$311 \wedge 110$	$36^\circ 44'$	$- 36^\circ 45'$	$36^\circ 44' 30''$	$36^\circ 15' 20''$
$x \wedge m'''$	$311 \wedge 1\bar{1}0$	$49^\circ 28'$	$- 49^\circ 23'$	$49^\circ 24' 30''$	$49^\circ 24'$

Physical properties. — The crystals are extremely brittle, breaking with a conchoidal fracture, but with no apparent cleavage. The luster is vitreous. They vary from colorless to white, but are often darkened by impurities. The hardness

is between 3 and 3.5. The specific gravity, taken by suspension in methylen iodide, was found to be 2.352.

The crystals exhibit the phenomenon of pyroelectricity in a marked degree. While cooling, after being gently heated, the extremity upon which the acute pyramid e (131) is developed, became negatively electrified. This was shown by dusting with a mixture of red oxide of lead and sulphur, as recommended by Kundt.*

Optical properties. — The plane of the optic axes is the base and the axis b is the acute bisectrix. The optical orientation is $a = a$, $b = c$ and $c = b$. The double refraction is positive and strong. The dispersion is slight $\rho < v$.

For the determination of the indices of refraction the method of total reflection was employed, making use of a crystal upon which a large pinacoid face, b (010) was developed. The plate was measured in a monobromnaphthalene, whose index of refraction for yellow, Na, was found to be 1.6588 at 23° C. The values obtained were:

$$\begin{aligned}\text{For yellow, Na, } a &= 1.5043 \\ \beta &= 1.5095 \\ \gamma &= 1.5751\end{aligned}$$

By means of the three indices of refraction the value of $V_{a,y}$ was calculated and found to be 16° 24'.

With a prism of 56° 41', whose faces were approximately parallel to 110 and $\bar{1}10$, the values of β and γ for red, Li; yellow, Na; and green, Tl, were also obtained.

	β	γ
Red	1.5056	1.5710
Yellow	1.5084	1.5747
Green	1.5115	1.5789

The value of β for yellow is probably not as accurate as that obtained by means of total reflection.

The divergence of the optical axes, $2E$, was measured on a plate parallel to 010. The values that were obtained are as follows:

* Ann. d. Phys. u. Chem., xx, p. 592, 1883.

	Red, Li.	Yellow, Na.	Green, Tl.
2 E at 25°C =	47° 45'	48° 14'	48° 22'
Hence 2V =	31° 11½'	31° 26'	31° 27'

The value of $V_{a.y}$ is 15° 43' and agrees favorably with the value 16° 24' obtained by calculation from the three indices of refraction.

It was observed that the angle 2 E varied somewhat, and to determine to what extent this was dependent upon the temperature the following measurements were made:

Temperature	20°	30°	40°	50°	60°	70°	90° C.
2 E _y	= 48°16'	48°10'	48°4'	47°55'	47°50'	47°45'	47°38'

Chemical composition.—Suitable material for analysis was readily obtained and the results are as follows:

	I.	Found. II.	Average.	Ratio.	
CO ₂	36.23	35.91	36.07	0.819	2.00
CaO	23.28	23.48	23.38	0.417	1.02
Na ₂ O	25.69	25.71	25.70	0.414	} 0.416 1.02
K ₂ O	0.17	0.13	0.15	0.002	
H ₂ O	14.74	14.73	14.73	0.818	2.00
Al ₂ O ₃ , etc.	. . .	0.13	0.13	. . .	
SiO ₂	0.36	0.22	0.29	. . .	
			100.45		

The ratio for CO₂ : CaO : Na₂O : H₂O is very close to 2 : 1 : 1 : 2, which gives the formula CaCO₃ . Na₂CO₃ . 2H₂O. The theoretical composition is given below, together with the analysis, after deducting impurities, substituting for K₂O its equivalent of Na₂O, and recalculating to 100 per cent.

	Found.	Calculated for CaCO ₃ . Na ₂ CO ₃ . 2H ₂ O.
CO ₂	36.08	36.36
CaO	23.39	23.14
Na ₂ O	25.80	25.62
H ₂ O	14.73	14.88
	100.00	100.00

The chemical composition of this mineral differs from gay-lussite, $\text{CaCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 5\text{H}_2\text{O}$, in having only two instead of five molecules of water of crystallization. Experiments that were made to determine at what temperature the water is driven off from the air-dry powder are as follows:

	Loss.
Six hours at 100° . . .	Nothing
Ten hours at 150° . .	13.85
Three hours at 200° .	0.37
Six hours at 250° . . .	0.36
Below faint redness . .	0.16
Total	14.74

As practically all of the water is expelled below 150°, it must be regarded as water of crystallization.

In Analysis I the water was weighed directly by the method described by Penfield,* and in II it was determined by loss on gentle ignition.

Pyrognostics. — The mineral decrepitates when heated before the blowpipe, and fuses about 2–2.5, coloring the flame intensely yellow. It reacts alkaline after heating. In the closed tube it decrepitates and gives off water at a low temperature. It is soluble in cold dilute hydrochloric and nitric acids with effervescence.

Name. — The author takes pleasure in naming this mineral *pirssonite*, in honor of his friend and associate, Professor L. V. Pirsson, of the Sheffield Scientific School.

HANKSITE.

This mineral was first identified in 1885 by Mr. W. E. Hidden,† who observed some crystals with hexagonal habit marked thenardite, in the mineral exhibit from California, at the World's Industrial and Cotton Centennial Exposition, held in New Orleans. Upon examination these crystals proved to be a new mineral, to which the name, *hanksite*, was

* Amer. Jour. Sci., 1894, vol. 48, p. 31.

† Amer. Jour. Sci., 1885, vol. 30, p. 33.

given, in honor of Mr. H. G. Hanks, formerly State Mineralogist of California.

The mineral occurs at Borax Lake in many places. According to information received from Mr. Northup, short crystals with prominent basal planes are found near the surface, either attached to the under side of the crust, already referred to on page 262 of this article, or in the mud directly beneath this. The habit of these crystals is illustrated by figures in the articles by Hidden and Hanks.* Beneath the crust, for a distance of about 50 feet, hanksite crystals are rare, but at this depth a stratum of mud was encountered, containing a few crystals with a habit somewhat resembling quartz, shown in Figure 7. The crystals were etched to such an extent that they could not be measured with the reflection goniometer, but by means of the contact goniometer the forms were identified as the prism m ($10\bar{1}0$) and the unit pyramid o ($10\bar{1}1$).

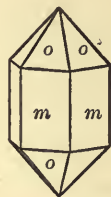


FIGURE 7.

Optical properties. — As the indices of refraction of hanksite had not been determined, a basal section was prepared from a tabular crystal, and by means of total reflection the following values were obtained:

For yellow, Na, $\omega = 1.4807$ $\epsilon = 1.4614$.

The section showed a normal uniaxial interference figure and a strong negative double refraction.

Chemical composition. — Our knowledge concerning the chemical composition of hanksite is confined to two analyses. One by Mackintosh, quoted by Hidden,† from which the formula, $4\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3 \cdot \frac{1}{2}\text{NaCl}$ was derived. Sodium chloride, however, was regarded as non-essential and $4\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$ was suggested as the probable formula. It should be pointed out, however, that a mistake in the calculation of the analysis was made, for while the ratio of $\text{Na}_2\text{SO}_4 : \text{Na}_2\text{CO}_3 : \text{NaCl}$ is given as 3.95 : 1 : 0.46 or 4 : 1 : 0.5, it should have

* Amer. Jour. Sci., 1889, vol. 37, p. 66.

† Amer. Jour. Sci., 1885, vol. 30, p. 134.

been 4.6 : 1 : 0.53. The analysis is also incomplete since the bases are calculated wholly as soda.

An analysis has also been made by Penfield * on material from a large crystal presented to the Brush collection by the late Prof. J. S. Newberry. It was quite impure, apparently owing to included clay, the analysis giving 4.41 per cent of insoluble material and 1.32 per cent loss on ignition. In addition to sodium, 2.33 per cent of potassium was determined, which is just sufficient to unite with the 2.13 per cent of chlorine to form potassium chloride. An examination of a section of this crystal by Prof. E. S. Dana † showed numerous rectangular inclusions, supposed to be either sodium or potassium chloride. The material was regarded as too impure to warrant the establishment of a complicated formula, and the results of the analysis, after deducting the insoluble material, loss on ignition, and KCl, approximated to the formula $4\text{Na}_2\text{SO}_4 \cdot \text{Na}_2\text{CO}_3$, suggested by Mackintosh.

In making the optical examination of the hanksite it was observed by the present writer that although the sections, when examined with the microscope, showed trifling impurities, nothing of an isometric character could be detected. Moreover, on testing numerous crystals for chlorine, it was found to be invariably present, and since the results of Penfield and Mackintosh have shown that the mineral contains an amount of chlorine corresponding to over 4 per cent of sodium or potassium chloride, it is not possible that either of these latter compounds could be present to such an extent, as an impurity, without being detected with the microscope. It was suggested, therefore, by Prof. Penfield, that new analyses, made on the exceptionally pure material now at hand, might indicate that chlorine is an essential constituent of the mineral.

Some flat tabular crystals were therefore selected, and in order to free them as far as possible from any impurities they might contain, they were crushed and sifted to a uniform grain and separated by means of methylen iodide. Most of the material varied in specific gravity between the narrow

* Amer. Jour. Sci., 1885, vol. 30, p. 137.

† Loc. cit.

limits 2.567 and 2.553, and this alone was used for the analysis.

The prismatic crystals, derived from the stratum of mud fifty feet below the surface, having the habit shown in Figure 7, appeared even purer than those mentioned above, and, fortunately, enough of these had been supplied by Mr. Northup for an analysis. The specific gravity was found to be 2.545.

The results of the analyses of the two samples are as follows:

	Tabular Crystals.		Average.	Ratio.		Prismatic Crystals.			
	I.	II.				III.	Ratio.		
SO ₃ .	45.89	...	45.98	45.93	0.574	9.00	45.78	0.572	9.00
CO ₂	...	5.65	...	5.65	0.128	2.01	5.63	0.128	2.01
Na ₂ O	43.27	...	43.43	43.35	0.699	10.95	43.61	0.703	11.07
Cl	...	2.21	...	2.21	0.062	0.97	2.28	0.064	1.01
K	2.40	...	2.55	2.43	0.063	0.98	2.39	0.061	0.96
Insol.	0.22	...	0.16	0.19			0.12		

The analyses are almost identical, indicating that chlorine and potassium are not accidental constituents. The ratios of SO₃ : CO₂ : Na₂O : Cl : K are very close to 9 : 2 : 11 : 1 : 1 corresponding to the formula 9Na₂SO₄ . 2Na₂CO₃ . KCl.

Of the previous analyses, that of Mackintosh yields the ratio of SO₃ : CO₂ : Cl = 9 : 1.93 : 1.04, fully supporting the above formula, but no further comparison can be made, as the bases were calculated wholly as soda. The analysis of Penfield gives the ratio SO₃ : CO₂ : Na₂O : Cl : K = 9 : 2.03 : 10.89 : 0.99 : 0.99, which is fully in accordance with the above formula.

Further, in order to show the close agreement between the analytical results and the theoretical composition, the analyses with the exception of that of Mackintosh are given below, after deducting impurities and recalculating to 100 per cent.

	Tabular Crystals.	Prismatic Crystals.	Penfield's.	Theory.
SO ₃	46.11	45.92	46.21	46.02
CO ₂	5.66	5.65	5.74	5.62
Na ₂ O	43.53	43.74	43.32	43.59
Cl	2.215	2.29	2.26	2.26
K	2.485	2.40	2.47	2.49
	<u>100.000</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>

With the close agreement of these three complete analyses, together with the partial one of Mackintosh, made on entirely different samples, on crystals collected at different times and from different parts of the deposit, there can be no doubt that both potassium and chlorine are essential constituents of the compound and the somewhat complicated formula, $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$ is the correct one. It is scarcely possible that potassium and sodium are isomorphous in this mineral, for potassium seems always to be present in quantity just sufficient to form KCl with the chlorine. The compound furnishes a very interesting example of the exceptionally rare occurrence of three acid radicals in a mineral.

In conclusion, the author wishes to express his indebtedness to Professor Penfield for his valuable advice and assistance, and also for his very kind interest in the work, throughout the entire investigation.

ON WELLSITE, A NEW MINERAL.

By J. H. PRATT AND H. W. FOOTE.

(From Amer. Jour. Sci., 1897, vol. 3, 443-448.)

THE mineral to be described in this article occurs at the Buck Creek (Cullakanee) corundum mine in Clay Co., North Carolina, and was collected by Professor S. L. Penfield and one of the present writers (Pratt) during the summer of 1892 while engaged in work on the North Carolina Geological Survey.

The corundum vein in which the mineral is found is composed chiefly of albite, feldspar, and hornblende, and penetrates a peridotite rock, dunite, near its contact with the gneiss. The peridotite outcrop is one of the largest in the State and has been thoroughly prospected for corundum. At only one of the veins opened was the new mineral found, although a careful search was made for it at all the openings, especially those affording feldspar. No mining has been done at the locality since 1891, but if work is resumed and the veins uncovered, more of the material will undoubtedly be found.

The mineral is found in isolated crystals mostly attached to the feldspar but also to hornblende and corundum, and is intimately associated with chabazite which occurs in small transparent rhombohedrons.

The largest crystals that were observed were not over 1 mm. in diameter and 2 mm. in length.

Crystalline form. — The crystals belong to the monoclinic system and they are twinned similarly to those of harmotome and phillipsite. The common habit is shown in Figure 1, which represents a combination of twinning about c (001) and e (011). The crystals are practically square prisms, terminated by pyramidal faces, thus imitating closely a simple combination of a prism of one order and a pyramid of the other in

the tetragonal system. The apparent prismatic faces are formed for the most part by the pinacoid faces, b , but the crystals interpenetrate each other somewhat irregularly, so that portions of the base c (001) coincide with b , Figure 1. The lines of twinning on the pinacoid faces between b and b twinned are generally regular, while those between b and c and also those which cross the prism faces m (110) (the apparent pyramid) are generally quite irregular. The b faces do not show the striations parallel to the edges b and m , which, meeting along the twinning lines, often reveal the complex nature of such crystals, nor were any reëntrant angles observed parallel to the edges of the apparent prism as are common on phillipsite and harmotome.

Figure 2 represents another habit of the crystals where m (110) is wanting and a (100) is in combination with b (010). The method of twinning is similar to that already described, but the crystals being terminated by a (100) instead of m (110) show prominent reëntrant angles at their ends. These crystals are very similar to those of harmotome from Bowling near Dumbarton, on the Clyde, described by Lacroix.*

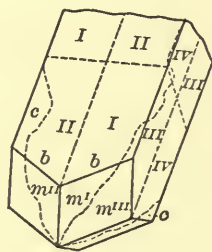


FIGURE 1.

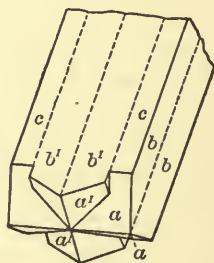


FIGURE 2.

The only forms that were observed were a (100), b (010), c (001), and m (110), with e (011) only as twinning plane.

The faces of the crystals are somewhat rounded and vicinal so that reflections were not very perfect. The angle of the apparent prism $b \wedge b$ twinned is approximately 90° . Also the angle $m \wedge m$ over the twinning plane (011) could be mea-

* Bull. Soc. Min. de France, No. 4, p. 94, 1885.

sured only approximately, varying from $0^{\circ} 49'$ to $1^{\circ} 25'$. The approximate angles are given below, and from those marked with asterisks the following axial ratio was calculated:

$$a : b : c = 0.768 : 1 : 1.245; \beta = 53^{\circ} 27' = 001 \wedge 100$$

	Measured.	Calculated.
$b \wedge b, 010 \wedge 010$	$*90^{\circ}$ (over twinning plane)	
$a \wedge a, 100 \wedge 100$	$*73^{\circ} 6'$ (over twinning plane)	
$b \wedge m, 010 \wedge 110$	$*58^{\circ} 19'$	
$c \wedge a, 001 \wedge 100$	$53^{\circ} 27' = \beta$	
$c \wedge m, 001 \wedge 110$	$60^{\circ} 00', 59^{\circ} 45', 59^{\circ} 57'$	$59^{\circ} 33'$

Physical properties.—The crystals are brittle and show no apparent cleavage. The luster is vitreous. Many of the crystals are colorless and transparent, while others are white. The hardness is between 4 and 4.5. The specific gravity taken on a number of separate crystals, by means of the heavy solution, varied between 2.278 and 2.366. This variation was probably due to the difference in the ratio of the barium to the calcium in the different crystals.

A section parallel to the pinacoid b (010), the apparent prism, revealed in polarized light the structure shown in Figure 3. The parts I and I extinguish simultaneously, as also II and II; while portions III, which are parallel to the basal plane, show parallel extinction. The section showed something of a zonal structure, so that the extinction could be measured only approximately. Using the Bertrand ocular, this was found to be 33° from one pinacoid on to the other over the twinning plane. The axis a makes an angle of 52° with the vertical axis c in the obtuse angle β .

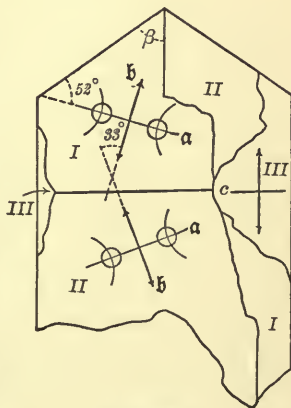


FIGURE 3.

The double refraction is positive and weak. The acute

bisectrix ϵ is at right angles to the pinacoid 010, and the divergence of the optical axes is large. 2E probably varies from 120° to 130° , but this could not be measured directly.

Chemical analysis. — The mineral was purified for analysis by means of the heavy solution and that which was used varied in specific gravity from 2.278 to 2.360. Water was determined by loss on ignition and silica and alumina by the ordinary methods after fusion with sodium carbonate. The filtrate from the alumina precipitation was evaporated with aqua regia to remove the large excess of ammonium salts and a small amount of ammonium chloride was again added. Calcium, barium and strontium were then precipitated together, with a considerable excess of ammonia and ammonium carbonate, and magnesia was determined in the filtrate. The mixed carbonates were dissolved in hydrochloric acid, evaporated to dryness and taken up in about 300 c. c. of water. The method used for separating barium was that recommended by Fresenius.* To the hot solution, a few drops of acetic acid were added and 10 c. c. of a 10 per cent solution of ammonium chromate containing a small amount of dichromate. After standing until the solution became cold, the clear liquid was decanted and the precipitate of barium chromate was washed with a weak chromate solution and with water. The precipitate was dissolved in 2 c. c. of pure dilute nitric acid, which was then partly neutralized with ammonia. Ammonium acetate was added and 10 c. c. of chromate solution as before, and after standing, the precipitate was filtered on a Gooch crucible and weighed as BaCrO_4 . The filtrate from the barium precipitation was concentrated somewhat, and calcium and the small quantity of strontium precipitated as before. They were ignited and weighed as oxide. Strontium was then separated by treatment with amyl alcohol and determined as sulphate. The alkalies were determined by a Smith fusion in the ordinary way.

The results of the analyses are as follows:

* Zeitschr. Anal. Chem. xxix, 426.

	I.		II.	Average.	Ratio.	
SiO ₂	43.62	...	44.11	43.86	0.731	3.00
Al ₂ O ₃	25.04	...	24.89	24.96	0.244	1.00
BaO	5.00	...	5.15	5.07	0.033	0.228 0.93
SrO	1.12	...	1.18	1.15	0.011	
CaO	5.76	...	5.84	5.80	0.104	
MgO	0.61	...	0.62	0.62	0.015	
K ₂ O	...	3.40	...	3.40	0.036	
Na ₂ O	...	1.80	...	1.80	0.029	3.04
H ₂ O	13.32	...	13.39	13.35	0.742	
				100.01		

The ratio of SiO₂ : Al₂O₃ : RO : H₂O is very close to 3 : 1 : 1 : 3, which gives the formula R''Al₂Si₃O₁₀ · 3H₂O. The ratio of BaO : CaO : K₂O + Na₂O in the above analyses is nearly 1 : 3 : 2 and the theoretical composition calculated for this ratio is given below together with the analysis after substituting for Na₂O its equivalent of K₂O, and for MgO and SrO their equivalents, respectively, of CaO and BaO, and then recalculating to 100 per cent.

Theory for R''Al ₂ Si ₃ O ₁₀ · 3H ₂ O where R is $\frac{1}{2}$ Ba, $\frac{2}{3}$ Ca, $\frac{1}{3}$ K.		
SiO ₂	43.12	42.87
Al ₂ O ₃	24.54	24.27
BaO	6.65	6.62
CaO	6.59	7.27
K ₂ O	5.98	6.10
H ₂ O	13.12	12.87
	100.00	100.00

Experiments were made to determine at what temperatures the water was driven off, and the results are given in the following table, the mineral being heated in each case until the weight became constant. The last trace of water could only be driven off by heating the mineral over the blast lamp.

	Loss.	
At 100° C.	nothing.	
125	1.93	} 4.33
175	1.48	
200	0.92	
260	2.45	} 3.69
295	1.24	
Red heat	4.96	} 5.29
Over blast lamp	0.33	
Total	13.31	

As is seen from the above, about one-third of the water, or one molecule, is given off between 100° and 200°, another third approximately between 200° and 300°, while the remainder is expelled only at an intense heat. This would indicate that the water exists in three different conditions in the molecule. If only that which is expelled below 200° be regarded as water of crystallization, the composition would be $H_4R''Al_2Si_3O_{12} + H_2O$.

That the new mineral would be closely related to the phillipsite group of the zeolites, was expected from the first, on account of its crystalline form, and this relation is very satisfactorily brought out by a comparison of the crystallographic properties and chemical composition.

They all have very nearly the same axial ratios:

	<i>a</i>	:	<i>b</i>	:	<i>c</i>	
Wellsite	0.768	:	1	:	1.245	$\beta = 53^\circ 27'$
Phillipsite	0.70949	:	1	:	1.2563	$\beta = 55^\circ 37'$
Harmotome	0.70315	:	1	:	1.2310	$\beta = 55^\circ 10'$
Stilbite	0.76227	:	1	:	1.19401	$\beta = 50^\circ 49\frac{3}{4}'$

In their habit and method of twinning, they are also very similar, all the crystals being uniformly penetration twins. This is especially noticeable between the new mineral and phillipsite and harmotome which are common as double twins with *c* (001) and *e* (011) as twinning planes.

The place of the mineral in the phillipsite group is clearly

shown by a comparison of their chemical compositions. Arranged in order of their proportions of silica and water to the bases, we have the following interesting series, in which R represents the bivalent elements:

Wellsite	$RAl_2Si_3O_{10} \cdot 3H_2O$
Phillipsite	$RAl_2Si_4O_{12} \cdot 4\frac{1}{2}H_2O$
Harmotome	$RAl_2Si_5O_{14} \cdot 5H_2O$
Stilbite	$RAl_2Si_6O_{16} \cdot 6H_2O$

The ratio of $RO : Al_2O_3$ is constant, 1 : 1, in the series, while the proportions of silica and water have a constant ratio, 1 : 1, between themselves, except in the case of phillipsite. As there is, however, considerable variation in the analyses of phillipsite, it is not improbable that the ratio of $SiO_2 : H_2O$, given as 4 : $4\frac{1}{2}$, should be, in some cases at least, 4 : 4. The minerals then form a gradual series, increasing in the proportions of SiO_2 and H_2O from wellsite to stilbite.*

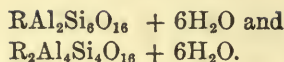
Fresenius † has shown that this group of minerals may be regarded as a series in which the ratio of $RO : Al_2O_3$ is constant, 1 : 1, while the silica and water vary between certain limits. He has assumed as these two limits:

* The following analysis of a very pure phillipsite from Bass Strait, South Australia, made by Mr. G. H. Edwards of the Sheffield Laboratory and here published for the first time, confirms the assumption made by Pratt and Foote that the ratio of $SiO_2 : H_2O$ in phillipsite is 4 : 4 and not 4 : $4\frac{1}{2}$:

	Specific gravity 2.218	Ratio.	
SiO_2	47.94	0.799	4.00
Al_2O_3	21.72	0.213	1.06
Fe_2O_3	0.44	...	...
BaO	0.77	0.007	0.196
SrO			
CaO	2.25	0.040	
Na_2O	2.73	0.044	
K_2O	9.87	0.105	
H_2O	14.92	0.829	4.14
	100.64		

The ratio $SiO_2 : Al_2O_3 : RO : H_2O$ approximates closely to 4 : 1 : 1 : 4, agreeing with the formula $RAl_2Si_4O_{12} \cdot 4H_2O$, R = K_2 , Na_2 , Ca, Ba, and Sr. — Editor.

† Zeitschr. Kryst., vol. 3, p. 42, 1878.



The first would be a hydrated calcium albite and the last a hydrated anorthite. From a comparison of the wellsite-stilbite series, it seems more probable that the anorthite end would be $\text{RAl}_2\text{Si}_2\text{O}_8 + 2\text{H}_2\text{O}$, or doubling this for better comparison with the formula of Fresenius, $\text{R}_2\text{Al}_4\text{Si}_4\text{O}_{16} + 4\text{H}_2\text{O}$.

It is not unreasonable to expect that the first or anorthite member of this series may be found in nature and the completed series would then be:

Anorthite limit . . .	$\text{RAl}_2\text{Si}_2\text{O}_8 + 2\text{H}_2\text{O}$ (not yet identified)
Wellsite	$\text{RAl}_2\text{Si}_3\text{O}_{10} + 3\text{H}_2\text{O}$
Phillipsite	$\text{RAl}_2\text{Si}_4\text{O}_{12} + 4\text{H}_2\text{O}$
Harmotome	$\text{RAl}_2\text{Si}_5\text{O}_{14} + 5\text{H}_2\text{O}$
Stilbite	$\text{RAl}_2\text{Si}_6\text{O}_{16} + 6\text{H}_2\text{O}$

It is also interesting to note that the formula of the new mineral wellsite is the same as that assigned to edingtonite, but the latter is essentially a barium mineral, and, being tetragonal, shows no crystallographic relations to wellsite.

Pyrognostics. — When heated before the blowpipe, wellsite exfoliates slightly and fuses at 2.5–3 to a white bead, coloring the flame slightly yellow. In the closed tube, water is given off at a low temperature. It is very readily decomposed by hot hydrochloric acid with the separation of silica, but without gelatinization. When the water in the mineral is driven off below 265° C., it is nearly all regained on exposing the mineral to the air. If the water, however, is driven off at a red heat, none is regained by the mineral.

Name. — It is with pleasure that the authors name this mineral *wellsite* in honor of their friend Professor H. L. Wells of the Sheffield Scientific School.

In conclusion, the authors wish to express their thanks to Professor Penfield for advice and suggestions and the kind interest he has shown during the investigation.

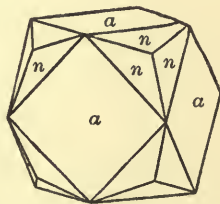
ON BIXBYITE, A NEW MINERAL.

BY S. L. PENFIELD AND H. W. FOOTE.

(From Amer. Jour. Sci., 1897, vol. 4, pp. 105-107.)

THE mineral to be described in the present article was sent to us for identification by Mr. Maynard Bixby, of Salt Lake City, Utah. Concerning its occurrence we are informed that the mineral is found very sparingly in one or two small areas on the edge of the desert about thirty-five miles southwest of Simpson, Utah. The crystals are implanted upon topaz and decomposed garnet and rhyolite, and have evidently been formed by fumarole action.

The mineral crystallizes in the isometric system, usually in cubes, some of which measure over 5 mm. on an edge. These are occasionally modified by the trapezohedron (211) and on one small specimen the cubes and trapezohedrons are developed with almost ideal symmetry as shown in the accompanying figure. When measured on the goniometer the crystals gave fairly good reflections of the signal, and $211 \wedge 112$ was found to be $33^{\circ}40'$: calculated $33^{\circ}33\frac{1}{2}'$. The mineral breaks with an irregular fracture, and on one or two specimens traces of octahedral cleavage were observed. The color is brilliant-black with metallic luster, and the streak is black. The hardness is 6 to 6.5. The specific gravity of the material used for the quantitative analysis was taken on a chemical balance and found to be 4.945. The mineral fuses before the blowpipe at about 4 and becomes magnetic. When very finely powdered, it dissolves with some difficulty in hydrochloric acid with evolution of chlorine.



Method of Analysis. — The material for analysis was separated in a nearly pure condition by the thallium-silver nitrate mixture. The mineral was treated with strong hydrochloric acid in a flask connected with a condenser, and the chlorine liberated was distilled over into a solution of potassium iodide. Free iodine was then determined volumetrically with standard thiosulphate and iodine solutions, from which the amount of available oxygen was calculated. After filtering off a small amount of insoluble material, iron, aluminium and titanium were separated from manganese and magnesium by the basic acetate method. The three oxides were weighed together, iron was then determined by titration with permanganate solution and titanium was twice precipitated by boiling the nearly neutral dilute sulphate solution for two hours in the presence of sulphur dioxide. It was weighed as TiO_2 . From the filtrate from the basic acetate precipitation, manganese was precipitated with excess of bromine water. The precipitate, after filtering, was dissolved in a solution of sulphur dioxide, precipitated as phosphate and weighed. Magnesium was precipitated from the first manganese filtrate as phosphate.

Following are the results of the analyses:

	I.	II.	Average.	Ratio.
SiO_2	1.24	1.19	1.21	. . .
Al_2O_3	2.57	2.48	2.53	. . .
Fe_2O_3	47.81	48.15	47.98	0.300
TiO_2	1.62	1.78	1.70	0.022
MnO	42.08	42.02	42.05	0.592
MgO	0.12	0.09	0.10	0.002
Available O	4.37	4.39	4.38	0.274
	99.81	100.10	99.95	

The silica and alumina are regarded as impurities, as only a trace of them went into solution when the mineral was treated with hydrochloric acid. In preparing the mineral for analysis, a variation in specific gravity was observed, owing to the fact that some of the dark particles were buoyed up by impurities, but in order to obtain sufficient material for analysis, it was

necessary to include some of the lighter portion. It is probable from the results of the analysis that some topaz was present, for the ratio of silica to alumina is about 1:1 and topaz is intimately associated with the bixbyite.

Leaving silica and alumina out of account, two formulas are possible. Considering the titanium as Ti_2O_3 , the oxygen derived from the TiO_2 , 0.16 per cent, plus the available oxygen, 4.38 (total 4.54 per cent) is about sufficient to convert the MnO into Mn_2O_3 , the amount required for 42.05 per cent MnO being 4.74. The composition therefore may be expressed as R_2O_3 , where $R = Fe, Mn$, and a little Ti . The proportion of Fe to Mn is 1:0.99 or almost 1:1, so that disregarding Ti_2O_3 , the composition is $FeMnO_3$. If the mineral is an isomorphous mixture of Fe_2O_3 , Mn_2O_3 and Ti_2O_3 we should expect it to be rhombohedral and to belong to the hematite and corundum group, and also it is not probable that the Fe and Mn would be present in the proportion 1:1.

As the mineral is isometric, it seems more reasonable to regard it as a compound having essentially the composition $FeO \cdot MnO_2$, and related to the isometric mineral perovskite, $CaO \cdot TiO_2$. On this basis, the results of the analysis may be put in the following shape:

	Ratio.	
FeO 43.17	0.600	} 0.602
MgO 0.10	0.002	
MnO 42.05	0.592	} 0.613
TiO_2 1.71	0.021	
Avail. O and O from Fe_2O_3 9.18	0.574	
SiO_2 1.21		
Al_2O_3 2.53		
	99.95	

The ratio of $Fe + Mg : Ti + Mn$ is 0.602:0.613 or nearly 1:1, while the oxygen is almost sufficient to convert the MnO into MnO_2 as indicated by the ratio $MnO : O = 0.592 : 0.574$. As oxygen was determined perhaps as accurately as any other constituent, it seems possible that a small amount of manganese may be present as protoxide, replacing FeO . If enough man-

ganese be taken as protoxide to make the ratio of RO to RO₂ exactly 1 : 1, the results become :

		Ratio.	
FeO	43.17	0.600	} 0.608
MgO	0.10	0.002	
MnO	0.40	0.006	
TiO ₂	1.71	0.021	} 0.608
MnO	41.65	0.587	
O	9.18		
SiO ₂	1.21		
Al ₂ O ₃	2.53		
	<u>99.95</u>		

The oxygen necessary to convert 41.65 per cent of MnO to MnO₂ is 9.38, which is only slightly in excess of that actually found in the analysis. It seems therefore probable that the mineral is essentially FeMnO₃ = FeO . MnO₂, in which small quantities of MgO and MnO are isomorphous with FeO and a little TiO₂ with MnO₂. The mineral is therefore to be regarded as a ferrous salt of manganous acid, H₂MnO₃, corresponding to braunite MnMnO₃, which is supposed to be the manganese salt of the same acid.

We take pleasure in naming this mineral after Mr. Bixby, who has generously supplied us with material for investigation, and has gone to a great deal of trouble and pains to secure the specimens.

ON THE CHEMICAL COMPOSITION OF HAMLINITE AND ITS OCCURRENCE WITH BERTRANDITE AT OXFORD COUNTY, MAINE.

By S. L. PENFIELD.

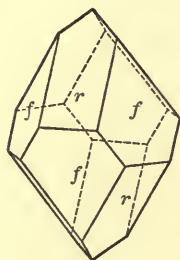
(From Amer. Jour. Sci., 1897, vol. 4, pp. 313-316.)

IN the summer of 1890, Mr. W. E. Hidden and the author published a short description of a rhombohedral phosphate occurring with the rare minerals herderite and bertrandite at Stoneham, Maine. Only a single specimen, showing a few minute crystals, was ever found at the locality, and the investigation was therefore incomplete, being confined to determinations of the crystallization and physical properties and the identification of phosphorus, aluminium, fluorine, and water, while from its association it was supposed that it would also contain beryllium.

The mineral was named *hamlinite* in honor of Augustus C. Hamlin of Bangor, Maine, who has always taken a keen interest in collecting and studying the minerals of his State, and especially the beautiful tourmalines from Mt. Mica and vicinity. As stated in the original article, the incomplete description was published for the purpose of calling attention to a mineral which would probably prove to be interesting, and also in hopes that others would be led to look for the mineral and find it. This hope has not been in vain, for Mr. Lazard Cahn of New York had the good fortune to discover among a suite of minerals from Oxford County, Maine, some specimens showing rhombohedral crystals of a mineral, unknown to him, which he gave to the author, suggesting that they might prove to be the rare mineral hamlinite. It is hoped that additional information may be obtained concerning the exact locality at which the mineral is found, so that a supply of specimens may become available for distribution. The mineral was readily

identified as hamlinite by its rhombohedral crystallization, basal cleavage, positive double refraction, and blowpipe reactions.

The crystals are implanted upon feldspar and muscovite and are associated, like the ones from Stoneham, with apatite, hercynite and rarely bertrandite. The crystals present two prominent habits: One a combination of the rhombohedrons $r(10\bar{1}1)$ and $f(02\bar{2}1)$, developed as shown in the accompanying figure.



On these crystals there are occasionally small basal planes and slight horizontal striations on the rhombohedral faces near their juncture with the base. The other habit is essentially a combination of the hexagonal prism of the first order ($10\bar{1}0$) with the base, but, owing to a vicinal development and rounding, the prismatic faces have a tendency toward a steep rhombohedral development, and the basal planes are marked by triangular prominences.

The crystals attain at times a diameter of 3 to 4 mm., but are not well adapted for measurement owing to the vicinal character of the faces. The following measurements can claim to be only approximations, since there were usually several reflections of the signal of the goniometer from each face, and it was impossible to tell upon which one the cross-hair of the telescope should be placed. The calculated angles are those derived from measurements of the hamlinite from Stoneham, $c = 1.135$, but the crystals from that locality showed a vicinal development of their faces, and the values cannot, therefore, be considered as very exact.

	Measured.	Calculated.
$r \wedge r, 10\bar{1}1 \wedge \bar{1}101 =$	$88^{\circ} 41'$	$87^{\circ} 2'$
$f \wedge f, 02\bar{2}1 \wedge \bar{2}021 =$	$109^{\circ} 11'$	$108^{\circ} 2'$
$r \wedge f, 10\bar{1}1 \wedge 02\bar{2}1 =$	$54^{\circ} 44' \text{ and } 54^{\circ} 47'$	$54^{\circ} 1'$

It was found to be practically impossible to select by hand-picking a sufficient quantity of the pure hamlinite crystals for an analysis, and, therefore, a number of specimens upon which the crystals were observed were pulverized, and the hamlinite

separated from the other minerals, by means of the heavy liquids. Apatite, however, could not be thus separated, but, owing to the fact that hamlinite is almost insoluble in boiling dilute hydrochloric acid, it was possible by treatment with successive portions of acid until the solution gave no test for calcium, to remove the apatite completely. All possible precautions were taken to make the separation and purification of the mineral as complete as possible, and the mineral, when examined with the microscope, showed no visible impurity. The specific gravity of the hamlinite varied considerably, that portion which was taken for the chemical analysis being between 3.159 and 3.283, while some of the mineral was still a trifle higher and some a little lower.

A qualitative analysis indicated the presence of aluminium, strontium, barium, phosphorus, fluorine, and water, and the absence of calcium and beryllium. In the quantitative analyses the strontium and barium were weighed together as sulphates and subsequently separated as recommended by Fresenius,* by a double precipitation of the barium as chromate. The fluorine was weighed as calcium fluoride, and the latter was tested and found to be pure by conversion into sulphate. Water was determined in two ways; first by fusing with dry sodium carbonate and weighing the water directly,† second by loss on ignition, using a weighed quantity of lime to retain the fluorine.‡ The air-dry powder lost only 0.16 per cent by heating to 100°, and the water was not expelled until the mineral was heated nearly to redness, thus indicating the presence of hydroxyl.

The results of the analysis are given on p. 290.

The ratio of $P_2O_5 : Al_2O_3 : (Sr + Ba)O : (OH + F)$ is very nearly 1 : 1.5 : 1 : 7, which gives the formula $Al_3Sr(OH)_7P_2O_7$, or better $[Al(OH)_2]_3[SrOH]P_2O_7$, where strontium is partially replaced by barium, and hydroxyl by fluorine.

By the method of preparing the mineral for analysis traces of adhering feldspar and mica could not be wholly avoided, and, although the small quantities of Fe_2O_3 and alkalis may

* Zeitschr. für anal. Chemie, xxix, p. 413, 1890.

† Amer. Jour. Sci., 1894, vol. 48, p. 37.

‡ Ibid., 1896, vol. 32, p. 109

					Average.	Ratio.		
P ₂ O ₅	...	...	28.92	...	28.92	0.204	1.00	
Al ₂ O ₃	32.29	32.30	...	...	32.30	0.316	1.55	
Fe ₂ O ₃	...	0.90	...	...	0.90	...	...	
SrO	18.33	18.53	...	...	18.43	0.178	} 0.204	1.00
BaO	4.10	3.89	...	...	4.00	0.026		
H ₂ O	...	...	11.93	12.07	12.00	÷ 9 = 1.333	} 1.435	7.03
F	1.93	...	...	...	1.93	0.102		
SiO ₂	0.96	...	...	...	0.96	...	...	...
K ₂ O	...	0.34	...	...	0.34	...	...	...
Na ₂ O	...	0.40	...	...	0.40	...	...	...
					<u>100.18</u>			
Oxygen equivalent of fluorine					0.81			
					99.37			

belong partly to the hamlinite and partly to impurities, these have been neglected in making the calculations. If the alkalis together with their equivalent of Al₂O₃ (1.06 per cent), the Fe₂O₃ and the SiO₂, in all 3.62 per cent, are deducted from the analysis and the remainder calculated to one hundred per cent, the results are as given below, where they are compared with the theoretical composition, where Sr : Ba = 7 : 1 and OH : F = 13 : 1.

	Found.	Calculated.
P ₂ O ₅	30.20	30.31
Al ₂ O ₃	32.67	32.65
SrO	19.25	19.29
BaO	4.18	4.08
H ₂ O	12.53	12.48
F	<u>2.01</u>	<u>2.04</u>
	100.84	100.85
O = F	0.84	0.85

In its chemical composition hamlinite holds a unique position among minerals, as strontium and barium have never before been observed as essential constituents of a phosphate, and this is the first time that a pyrophosphate has been recorded.

ON CLINOHEDRITE, A NEW MINERAL FROM FRANKLIN, N. J.

By S. L. PENFIELD AND H. W. FOOTE.

(From Amer. Jour. Sci., 1898, vol. 5, pp. 289-293.)

THE mineral that is to be described in the present paper was first brought to our notice in the autumn of 1896 by Mr. Frank L. Nason of West Haven, Conn., who sent a few specimens of it to the Mineralogical Laboratory of the Sheffield Scientific School for identification. When informed that the mineral was a new species Mr. Nason visited the locality for the special purpose of obtaining more material, but so little was found that it seemed best to postpone the investigation until more could be secured. About a year later Mr. E. P. Hancock of Burlington, N. J., sent some Franklin minerals to our laboratory for identification, among them specimens of the new mineral, and on learning the nature of the mineral he took a keen interest in having it investigated, generously placing at our disposal for that purpose the few specimens he had collected. A short time later Mr. W. F. Ferrier of Ottawa, Canada, also called our attention to an exceptionally fine specimen of the mineral, which he had had the good fortune to find at the locality.

The specimens were all obtained from the dump of one of the new shafts of the Trotter mine, and are supposed to have come from a depth of about one thousand feet. The mineral is associated with transparent prisms of green willemite, a massive variety of brown garnet, phlogopite mica, small yellow crystals of axinite, dull crystals of datolite, and a reddish-brown mineral, occurring in slender prismatic crystals, which is now being investigated, and proves to be a new silicate containing lead, iron, and calcium as essential constituents.

The crystallization is *monoclinic*, and the crystals are especially interesting as they belong to that division of the monoclinic system characterized by a plane of symmetry, but not an axis of symmetry, or to the class of crystals called by Groth * the "*domatische Klasse*." No form in this class consists of more than two faces, and the pinacoid $b(010)$ is the only one where the faces are parallel. The prevalence of forms without parallel faces gives to the crystals a peculiar *inclined-faced* character or appearance, which has suggested the name of the mineral, *clinohedrite* ($\kappa\lambda\acute{\iota}\nu\epsilon\iota\nu$, incline, and $\epsilon\delta\rho\alpha$, face). Very few examples of this kind of symmetry have been observed among mineral substances, the best being some crystals of pyroxene described by Williams.† Pyroxene, however, generally exhibits the normal or most highly developed type of monoclinic symmetry, and specimens which show the lower degree of symmetry are so rarely met with that it seems probable that they are only the result of an accidental development of a part of the crystal faces.

The crystals of clinohedrite on a specimen sent to us by Mr. Hancock were exceptionally fine and well adapted for crystallographic study. They were about 4 mm. long, and from 2 to 3 mm. in diameter, and had the habit represented by Figures 1 and 2, the latter being drawn with the pinacoid

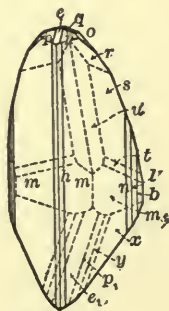


FIGURE 1.

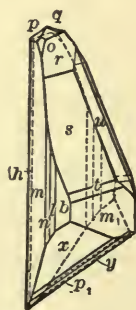


FIGURE 2.

* *Physikalische Krystallographie*, 3. Auflage, p. 356, 1895.

† *Amer. Jour. Sci.*, 1889, vol. 38, p. 115.

$b(010)$ in front. They were generally attached at the end represented as the lower one in the figures, and the forms at that end, when they could be observed, were rounded and graded into one another so that it was difficult to decide what ones were present and how they should be represented in the figure. At the upper, or free ends of the crystals, however, the faces were exceptionally perfect, and gave beautiful

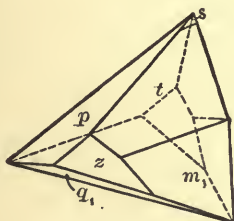


FIGURE 3.

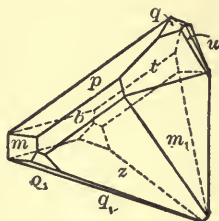


FIGURE 4.

reflections. The crystals on the specimens sent by Mr. Nason were not so well suited for crystallographic study, several of the forms being striated and rounded, and it was so difficult to obtain satisfactory measurements that the relations of the forms did not become wholly clear until the crystals from Mr. Hancock's specimen had been studied. Some of the crystals were 3 mm. in diameter, and Figures 3 and 4, drawn in the same position as Figure 2, will serve to exhibit the curious habit which they present.

The position which has been adopted seems well suited for representing the forms of the crystals which are given in the following table:

$b, 010$	$n, 120$	$p, 111$	$r, \bar{3}31$	$o, 1\bar{3}1$
$h, 320$	$l, 130$	$p_1, 1\bar{1}1$	$s, \bar{5}51$	$o_1, 13\bar{1}$
$m, 110$	$e, 101$	$q, 111$	$t, 771$	$x, 13\bar{1}$
$m_1, 110$	$e_1, 10\bar{1}$	$q_1, 11\bar{1}$	$u, \bar{3}31$	$y, 12\bar{1}$

The form z , Figures 3 and 4, is probably $1\bar{6}\bar{1}$, but no satisfactory measurements could be obtained from it.

The axial ratio was derived from the measurements marked by asterisks in the accompanying table, and is as follows:

$$a : b : c = 0.6826 : 1 : 0.3226; \beta = 100 \wedge 001 = 76^\circ 4'$$

Following is a list of measurements, together with the calculated angles:

	Calculated.	Measured.	Calculated angle on <i>b</i> , 010.	Measured angle on <i>b</i> , 010.
$m \wedge m, 110 \wedge 1\bar{1}0 =$	$67^\circ 2'$	$66^\circ 57'$	$56^\circ 29'$	$56^\circ 29'*$
$h \wedge h, 320 \wedge 3\bar{2}0 =$	$47^\circ 38'$	...	$66^\circ 11'$	$66^\circ 5'$
$n \wedge n, 120 \wedge 1\bar{2}0 =$	$105^\circ 54'$	...	$37^\circ 3'$	$37^\circ 12'$
$l \wedge l, 130 \wedge 1\bar{3}0 =$	$126^\circ 34'$	...	$26^\circ 43'$	$26^\circ 55'$
$p \wedge p, 111 \wedge 1\bar{1}1 =$	$29^\circ 8'$	$29^\circ 8'*$	$75^\circ 26'$	...
$q \wedge q, 111 \wedge 1\bar{1}1 =$	$34^\circ 52'$	$34^\circ 49'$	$72^\circ 34'$	$72^\circ 36'$
$r \wedge r, 331 \wedge 3\bar{3}1 =$	$63^\circ 15'$	$62^\circ 56'$	$58^\circ 22\frac{1}{2}'$	...
$s \wedge s, 551 \wedge 5\bar{5}1 =$	$67^\circ 43'$	$67^\circ 43'$	$56^\circ 8\frac{1}{2}'$	$56^\circ 20'$
$t \wedge t, 771 \wedge 7\bar{7}1 =$	$68^\circ 32'$	...	$55^\circ 44'$	...
$u \wedge u, 531 \wedge 5\bar{3}1 =$	$43^\circ 52'$	$44^\circ 6'$	$68^\circ 4'$	$68^\circ 0'$
$x \wedge x, 131 \wedge 1\bar{3}1 =$	$75^\circ 52'$	...	$52^\circ 4'$	$51^\circ 56'$
$y \wedge y, 121 \wedge 1\bar{2}1 =$	$54^\circ 56'$	...	$62^\circ 32'$	...
$p \wedge e, 111 \wedge 101 =$	$14^\circ 34'$	$14^\circ 36'$	...	...
$m \wedge p, 110 \wedge 111 =$	$51^\circ 54'$	$51^\circ 54'*$	...	...
$p \wedge q, 111 \wedge 1\bar{1}1 =$	$58^\circ 37'$	$58^\circ 29'$	...	...
$q \wedge r, 111 \wedge 331 =$	$36^\circ 21'$	$36^\circ 20'$	...	...
$r \wedge s, 331 \wedge 551 =$	$12^\circ 45'$	$12^\circ 44'$	...	...
$s \wedge t, 551 \wedge 771 =$	$5^\circ 50'$	$5^\circ 47'$	...	...
$y \wedge e_1, 121 \wedge 101 =$	$27^\circ 28'$	$27^\circ 42'$	...	...
$b \wedge o, 010 \wedge 131 =$	$46^\circ 43'$	$46^\circ 43'$	...	...

The cleavage is perfect by parallel to the pinacoid *b*, 010, but is not often observed. The hardness is 5.5 and the specific gravity 3.33. Many of the crystals are transparent, and the color varies from amethystine to nearly colorless or white. The crystals exhibit very distinctly the phenomenon of pyroelectricity when tested with the red oxide of lead and sulphur method described by Kundt.† On cooling a crystal of the

* Fundamental angles.

† Ann. d. Phys. u. Chem. xx, p. 592, 1883.

type represented by Figures 1 and 2 the p , e , and the upper extremities of the m faces in front became positively electrified and attracted the particles of sulphur, while the diagonally opposite faces x , y , p_1 , e_1 , and the lower extremities of m_1 became negatively electrified and attracted the red oxide of lead.

A section parallel to the pinacoid (010) when examined in polarized light showed an extinction of about 28° from the vertical axis in the obtuse angle β , and this direction corresponds to **b**. The plane of the optical axes is at right angles to (010). The crystallographic axis b is the obtuse bisectrix, and corresponds to **c**. The double refraction is not very strong, and is negative.

Material for the chemical analysis was first carefully selected by hand picking, and was then further purified by pulverizing and separating by means of the barium mercuric iodide solution. That portion which was used for the analysis varied in specific gravity between 3.344 and 3.327.

The method of analysis was as follows: Water was determined as loss on ignition, and the residue, after fusion with sodium carbonate, was dissolved in hydrochloric acid. The solution was evaporated twice to separate the silica, and in the filtrate from the silica the acid was neutralized with a slight excess of ammonia, formic acid of specific gravity 1.12 was added so as to make about one-fourth of the final volume, and hydrogen sulphide was passed into the hot solution until the zinc was precipitated. After filtering, the zinc sulphide was dissolved in hydrochloric acid, and the zinc reprecipitated as carbonate and weighed as oxide. In the filtrate from the zinc the small quantities of iron and alumina were precipitated twice with ammonia. To the filtrates acidified with hydrochloric acid bromine was added, and on making alkaline and heating to boiling all of the manganese was precipitated, but as it carried a little calcium it was redissolved, precipitated from an acetic acid solution with bromine, and finally determined as pyrophosphate. Calcium and the trace of magnesium were separated and determined in the usual manner.

The results of the analysis by Foote are as follows:

	I.	II.	Average.	Ratio.		Theory for $H_2CaZnSiO_5$.
SiO_2	27.14	27.29	27.22		0.454 0.97	27.92
ZnO	37.43	37.46	37.44	0.462	} 0.469 1.00	37.67
MnO	0.49	0.50	0.50	0.007		
CaO	26.31	26.19	26.25	0.469	} 0.471 1.00	26.04
MgO	0.07	0.08	0.07	0.002		
H_2O	8.53	8.59	8.56	0.476		8.37
$(Fe, Al)_2O_3$	0.26	0.31	0.28	...	...	...
			100.32			100.00

The ratio of $SiO_2 : (Zn+Mn)O : (Ca+Mg)O : H_2O$ is very nearly 1 : 1 : 1 : 1, from which the formula $H_2ZnCaSiO_5$ is derived, in which the zinc and calcium are replaced to a slight extent by manganese and magnesium respectively. The formula may also be written $(ZnOH)(CaOH)SiO_3$, and that hydroxyl is present is proved by the fact that water is not expelled much below a faint redness. The formula is analogous to that of calamine $H_2Zn_2SiO_5$ or $(ZnOH)_2SiO_3$.

The pyrognostic properties are as follows: In the closed tube at a gentle heat the mineral is unchanged, but at a temperature approaching faint redness it exfoliates, whitens and gives off water. Heated before the blowpipe the mineral exfoliates at first, and then fuses at about 4 to a yellowish enamel. A coating of zinc oxide is obtained when the mineral is heated alone or with a little sodium carbonate on charcoal. The powdered material dissolves readily in hydrochloric acid, and gelatinous silica is obtained when the solution is evaporated.

In conclusion we take great pleasure in expressing our sincere thanks to Messrs. F. L. Nason and E. P. Hancock, who have generously placed at our disposal all of the specimens of this rare mineral which they have been able to collect.

ON THE CHEMICAL COMPOSITION OF TOURMALINE.

By S. L. PENFIELD AND H. W. FOOTE.*

(From Amer. Jour. Sci., 1899, vol. 7, pp. 97-125.)

INTRODUCTION AND HISTORICAL. — There is probably no common mineral whose chemical composition has proved more perplexing and been so little understood as tourmaline. Some reasons for this are, first, that the mineral presents certain peculiarities in chemical composition of an unusual nature; second, the analysis of tourmaline has been one of the difficult problems of analytical chemistry, hence reliable data for the calculation of the formula have not been easily obtained; and, lastly, although good analyses have been made, the results have not been thoroughly relied upon, nor have they been interpreted to the best advantage. The present investigation was undertaken, therefore, with the hope that by making a few analyses with the utmost possible care on tourmalines of exceptional purity, it would be possible to find a satisfactory explanation of the chemical composition of this interesting mineral.

In order to appreciate the problem in hand, it will be necessary to review briefly the work and the results of previous investigators.

The analyses of Vauquelin and Klaproth, made in the early part of this century, were naturally defective, because at the time they were made, lithium was unknown, it had not been discovered that tourmaline contained boron, and analytical methods were not perfected.

In 1818 the presence of boron was detected by Lampadius,†

* NOTE. — This article has been shortened by omitting a review of the analyses of Rammelsberg found on pp. 108-114 of the original article. — EDITOR.

† Ann. d. Phys. u. Chem., xxx, p. 107.

and in the same year Arfvedson * discovered the new alkali metal lithium, and showed its presence in spodumene, petalite and tourmaline.

In 1827 Gmelin † published analyses of ten varieties of tourmaline, but his results led to no satisfactory formula, although the essential constituents of the mineral, with the exception of the boric oxide, were determined with a considerable degree of accuracy.

In 1845 Hermann ‡ published the results of four analyses of tourmaline from Russian localities. He proved conclusively that the iron was ferrous, and not ferric as considered by previous investigators. Boric oxide was not directly determined, but estimated by difference, and the results compare favorably with the direct determinations made by our present methods. He was the first to point out that silica and boric oxide are present in the definite molecular proportion 4: 1. He erroneously decided that tourmaline contained carbon dioxide, the reasons being as follows: It was generally believed at that time that the mineral contained no water, as stated by Hermann, "*die Turmaline keine Spur davon enthalten*," and it is true that when fragments are tested by the usual method of heating to redness in a closed tube no water is obtained. It is only when the material is heated *intensely*, best as fine powder, that hydroxyl is decomposed and water given off. When Hermann dissolved fragments in a borax bead he observed that a gas was evolved, and, since it was believed that this could not be water vapor, he supposed that it must be carbon dioxide. Pains were taken to fuse some of the mineral in a tube with borax, and to conduct the gas into lime water, by which treatment a precipitate was obtained which effervesced with acids, but it is safe to assume that the carbon dioxide thus detected was derived from improperly purified air and not from the mineral.

In 1850 Rammelsberg § published the results of the analyses

* Schweigger's Jour. d. Chem. u. Phys., xxii, p. 111.

† Pogg. Ann., ix, p. 127.

‡ Journal für prakt. Chem., xxxv, p. 232.

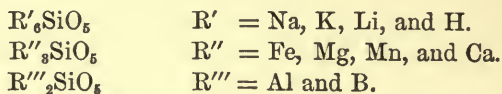
§ Ann. der Phys. u. Chem., lxxx, p. 449, and lxxxi, p. 1.

of thirty varieties of tourmaline. The execution of such a large number of analyses must be regarded as a very great undertaking, since at that time gas and many facilities of our modern laboratories were not available, and many methods of analysis were not perfected. Special evidence is given that great care was taken in the selection of material for analysis and in the analytical methods, which appear to have been well chosen and reliable in character. The analyses, however, were defective in several important particulars. Thus the iron was regarded chiefly as ferric. Believing, like Hermann, that tourmaline contained no water, and having detected the presence of fluorine in some varieties of the mineral, he supposed that the considerable loss on ignition which occurred was due to the volatilization of silicon fluoride, and from this loss he estimated fluorine to be present in amounts varying from 1.30 to 2.51 per cent. Direct determinations of boric oxide were made in three cases only, and in the remaining analyses this important constituent was estimated by difference. Although the analyses led to no satisfactory formula, they indicated certain prominent characteristics of the mineral, namely, the great variation in the relative amounts of aluminium, iron, magnesium and alkalis, and the nearly uniform amounts of silica and boric oxide.

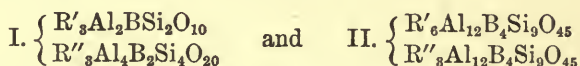
Fully realizing certain defects in his earlier analyses, Rammelsberg* published in 1870 a revision of his former paper. At this time it was shown that all varieties of tourmaline contained chemically combined water, and the amount of water was estimated from the earlier determinations of the loss on ignition after making certain corrections for volatilization of silicon fluoride. He found that the iron was chiefly if not wholly ferrous, and recalculated accordingly his earlier results. Six direct determinations of boric oxide were made, and it is pointed out that these amounts correspond closely with the indirect determinations by difference. As a result of the revision, Rammelsberg reached the conclusion that all tourmalines are derived from the acid H_6SiO_6 . In this he considered the

* Ann. der Phys. u. Chem., ccxv, pp. 379 and 547.

hydrogen atoms to be replaced by metals of different valences, or, in other words, he regarded tourmaline as composed of a mixture of the following molecules :



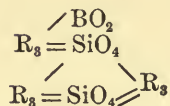
Furthermore he decided that certain varieties correspond closely to the special formulas



while he regarded others as mixtures of these two molecules. By substituting hydrogen atoms for the metals and boron of these special formulas, the acids become respectively $\text{H}_{24}\text{Si}_4\text{O}_{20}$ and $\text{H}_{64}\text{Si}_9\text{O}_{45}$, both of which are multiples of H_6SiO_5 . He concluded that the SiO_2 and B_2O_3 are not present in a definite molecular proportion, but that boron plays the part of a metal and is isomorphous with aluminium.

In 1888 Riggs * published the results of twenty analyses of various types of tourmaline from American localities. The analyses were executed in the laboratory of the U. S. Geological Survey at Washington, and bear every evidence of being made with the precision and care characteristic of the analytical work of that laboratory. Boric oxide, water, and ferrous oxide were determined directly by reliable methods, and a high degree of accuracy is claimed for the analyses. A careful description of the quality of the material analyzed is not given, and although it is to be supposed that great care was taken in its selection, the following statement has left this in doubt: "The analyses do not represent ideal compounds, but are made of material more or less impure" Riggs concludes that the analyses give "as a general tourmaline formula the simple boro-orthosilicate $\text{R}_3\text{BO}_2\text{SiO}_4$ " which is expressed graphically as follows:

* Amer. Jour. Sci., 1888, vol. 35, p. 35.



He supposes R to include H, Li, Na, K, Ca, Mg, Fe, Al, and small amounts of the (Al=O) or possibly (Al-OH) radicals. It may here be stated that the foregoing formula is identical in type with the special formula $\text{R}'_3\text{Al}_2\text{BSi}_2\text{O}_{10}$ ($\text{H}_9\text{BSi}_2\text{O}_{10}$) of Rammelsberg, and, considering boron as replacing hydrogen like a metal, the silicic acid from which the formula is derived becomes $\text{H}_{12}\text{Si}_2\text{O}_{10}$ or H_6SiO_5 . Riggs further states that, owing to slight variations, the ratios give nearly the "equally simple general formula $\text{R}_{10}\text{BO}_2\text{2SiO}_4$," stating that "between these two views there are at present no means at hand of deciding." It would seem, however, that the last formula is impossible, for, considering hydrogen atoms as replacing R_{10} the acid can not be split up like other oxygen acids into silicic and boracic anhydrides and water. There are also given the following special formulas for three pronounced types of tourmaline:

- I. Lithia tour. $12\text{SiO}_2 \cdot 3\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O} \cdot 8\text{Al}_2\text{O}_3 \cdot 2(\text{Na}, \text{Li})_2\text{O}$.
- II. Iron tour. $12\text{SiO}_2 \cdot 3\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O} \cdot 7\text{Al}_2\text{O}_3 \cdot 4\text{FeO} \cdot \text{Na}_2\text{O}$.
- III. Mg tour. $12\text{SiO}_2 \cdot 3\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O} \cdot 5\text{Al}_2\text{O}_3 \cdot \frac{2}{3}\text{MgO} \cdot \frac{2}{3}\text{Na}_2\text{O}$.

By substituting hydrogen atoms for the metals in these special formulas we obtain:

- I. and II. $\text{H}_{60}\text{B}_6\text{Si}_{12}\text{O}_{63}$ or $\text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{21}$.
- III. $\text{H}_{58}\text{B}_6\text{Si}_{12}\text{O}_{62}$ or $\text{H}_{19\frac{1}{3}}\text{B}_2\text{Si}_4\text{O}_{20\frac{2}{3}}$.

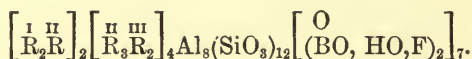
Soon after the appearance of Riggs' article, Wülfing* recalculated the results of these twenty analyses and concluded that all tourmalines may be regarded as isomorphous mixtures of two aluminium silicates, "*Alumosilicate*," of the following composition.

- I. Alkali tourmaline $12\text{SiO}_2 \cdot 3\text{B}_2\text{O}_3 \cdot 8\text{Al}_2\text{O}_3 \cdot 2\text{Na}_2\text{O} \cdot 4\text{H}_2\text{O}$.
- II. Magnesia tourmaline $12\text{SiO}_2 \cdot 3\text{B}_2\text{O}_3 \cdot 5\text{Al}_2\text{O}_3 \cdot 12\text{MgO} \cdot 3\text{H}_2\text{O}$.

* Mineralogische und petrographische Mittheilungen, x, p. 161.

In these formulas it is assumed that the isomorphous elements K and Li replace the Na; Fe''' the Al; and Fe'', Mn and Ca the Mg. By substituting hydrogen atoms for the metals in the foregoing formulas it is found that they both are derivatives of the same acid, $H_{60}B_6Si_{12}O_{63}$ or $H_{20}B_2Si_4O_{21}$. The conclusions derived by Wülfing are that, although in most cases the results of the analyses agree with the percentage values calculated from his formulas, the agreement is not always satisfactory. This he ascribes to the possible need of a third formula; to possible inaccuracies in the difficult ferrous iron determinations; and in part to the fact, as stated by Riggs, that "the analyses do not represent ideal compounds. . . ." He therefore considers it necessary that further analyses of more carefully selected materials should be made.

At about this time also Scharizer * published analyses of three varieties of tourmaline from Schüttenhofen, Bohemia, and discussed his results in connection with the analyses of Riggs. His final conclusion is that, with the exception of the green varieties, tourmalines possess a chemical constitution which can be expressed by the general formula:

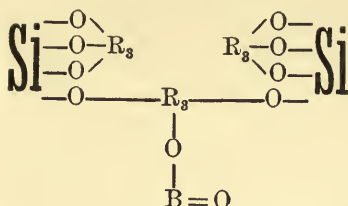


This formula is certainly difficult to comprehend, and if we understand it correctly, the univalent radicals BO and HO are isomorphous with fluorine, and these constituents, taken twice, can replace oxygen.

In 1889 Jannasch and Kalb † published the results of nine tourmaline analyses, in which the water and boron were determined directly. These investigators derived from their analyses the general formula $R_9 \cdot BO_2 \cdot (SiO_4)_2$, for which the following structural formula was proposed:

* Zeitschr. für Kryst., xv, p. 343.

† Berichte der deutschen chemischen Gesellschaft, vol. xxii, p. 216. Also Inaugural Dissertation, Geo. W. Kalb, Göttingen.



This formula, $\text{R}_3 \cdot \text{BO}_2 \cdot (\text{SiO}_4)_2$, is identical with the one proposed by Riggs, and essentially like the special formula $\text{R}'_3\text{Al}_2\text{BSi}_2\text{O}_{10}$ of Rammelsberg. The following special formulas are also given :

- I. Li tour. $24\text{SiO}_2 \cdot 6\text{B}_2\text{O}_3 \cdot 15\text{Al}_2\text{O}_3 \cdot 4\text{FeO} \cdot 4(\text{Li}_2\text{O}, \text{Na}_2\text{O}) \cdot 7\text{H}_2\text{O}$
 II. Fe tour. $24\text{SiO}_2 \cdot 6\text{B}_2\text{O}_3 \cdot 14\text{Al}_2\text{O}_3 \cdot 9\text{FeO} \cdot 2\text{Na}_2\text{O} \cdot 7\text{H}_2\text{O}$
 III. Fe-Mg tour. $24\text{SiO}_2 \cdot 6\text{B}_2\text{O}_3 \cdot 13\text{Al}_2\text{O}_3 \cdot 12\text{MgO} \cdot 2\text{Na}_2\text{O} \cdot 7\text{H}_2\text{O}$

These special formulas in their general type are similar to those proposed by Riggs. By substituting hydrogen atoms for the metals they all reduce to one and the same acid, $\text{H}_{120}\text{B}_{12}\text{Si}_{24}\text{O}_{126}$ or $\text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{21}$.

There is evidence that Jannasch does not place great confidence in the foregoing formulas, for in Hintze's Mineralogy* the composition is expressed as follows :

- | | |
|--------------------------|--|
| I. Lithia tourmaline | $\text{Si}_{12}\text{O}_{63}\text{B}_6\text{Al}_{15}(\text{Na}, \text{Li})_4\text{H}_7$ |
| II. Iron tourmaline | $\text{Si}_{12}\text{O}_{67\frac{1}{2}}\text{B}_6\text{Al}_{14}\text{Fe}_9\text{Na}_2\text{H}_7$ |
| III. Magnesia tourmaline | $\text{Si}_{12}\text{O}_{69}\text{B}_6\text{Al}_{13}\text{Mg}_{12}\text{Na}_2\text{H}_7$ |

These formulas are essentially different from the ones first proposed, which may readily be seen by substituting hydrogen atoms for the metals and comparing the resulting acids, as follows :

- I. $\text{H}_{56}\text{B}_6\text{Si}_{12}\text{O}_{63}$ or $\text{H}_{18\frac{2}{3}}\text{B}_2\text{Si}_4\text{O}_{21}$
 II. $\text{H}_{69}\text{B}_6\text{Si}_{12}\text{O}_{67\frac{1}{2}}$ or $\text{H}_{23}\text{B}_2\text{Si}_4\text{O}_{22\frac{1}{2}}$
 III. $\text{H}_{72}\text{B}_6\text{Si}_{12}\text{O}_{69}$ or $\text{H}_{24}\text{B}_2\text{Si}_4\text{O}_{23}$

Soon after the appearance of the articles of Riggs and of Jannasch and Kalb, the results of their analyses were recalculated.

* Vol. ii, p. 311 (communication by manuscript from Jannasch).

lated by Goldschmidt,* and the conclusion was reached that tourmaline may be regarded as containing the two following molecules:

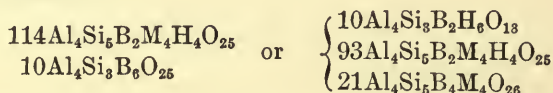
- | | |
|-------------------------|--|
| I. Alkali tourmaline | $R'_{32}R'''_{56}Si_{81}O_{162}$ |
| II. Magnesia tourmaline | $R'_{20}R''_{24}R'''_{44}Si_{81}O_{162}$ |

These formulas are both derived from an acid $H_{200}Si_{81}O_{162}$ or $H_{6.46}SiO_{5.23}$.

In 1893 Rheineck,† after calculating the results of the many tourmaline analyses, concluded that the composition of all tourmalines may be expressed by formulas of the following type, in which Al_4 appears as a constant:

- | | |
|--------------------------|----------------------------------|
| I. Alkali tourmaline | $Al_4Si_3BH_3O_{15}$ |
| II. Alkali tourmaline | $Al_4Si_3B_2H_4O_{17}$ |
| III. Magnesia tourmaline | $Al_4Si_5B_2M_4H_4O_{25}$, etc. |

M represents the bivalent metals Fe, Mn, Mg and Ca. H includes Na, Li, and K. Among the numerous examples he stated that the composition of the black tourmaline from Pierrepont, N. Y., may be represented by either of the following expressions:

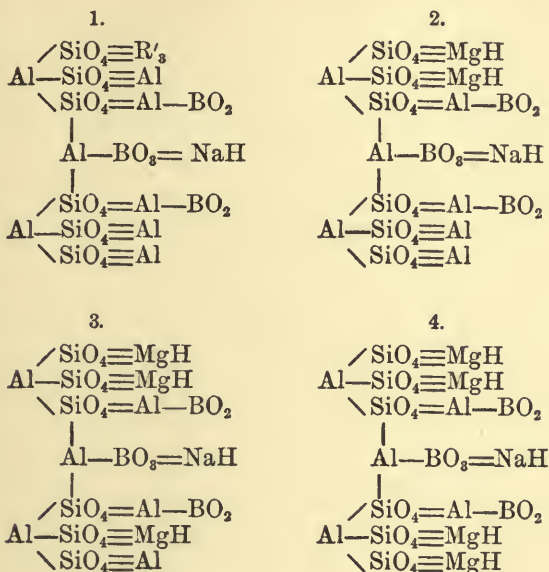


By substituting hydrogen atoms for the metals in these expressions, and multiplying by the factors, 114 and 10 in the one case, and 10, 93 and 21 in the other, the acids become $H_{2356}B_{288}Si_{600}O_{3100}$ and $H_{2332}B_{260}Si_{860}O_{3051}$, or, when simplified $H_{19.0}B_{1.9}Si_4O_{20.6}$ and $H_{18.9}B_{1.9}Si_4O_{20.3}$. The improbable nature of such acids is evident. In the opening paragraph of his article, Rheineck stated that the obscure and complex chemical relations of this mineral have necessitated a series of speculations and calculations extending somewhat interruptedly over a period of many years, in order to arrive at results such as those embodied in the foregoing formulas.

* Zeitschr. für Kryst., xvii, pp. 52 and 61.

† Zeitschr. für Kryst., xxii, p. 52.

In 1895 Clarke* discussed the constitution of tourmaline and proposed the following formulas:

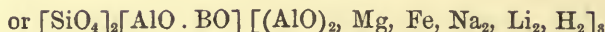
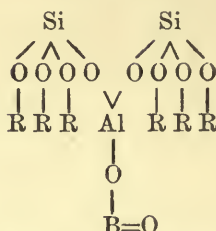


Clarke assumes variations from these formulas in that Fe''' and Cr can replace the Al; Fe'' and Mn the Mg; Ca the NaH and small amounts of F the BO₂. Proof of a constitution corresponding to the formulas cannot of course be expected, but it is doubtful whether aluminium could exercise such varied functions as the formulas indicate. The grounds for believing that fluorine can replace BO₂ are not stated. The acid from which all these formulas are derived is H₂₃B₈Si₆O₃₁ or H_{19.33}B₂Si₄O_{20.66}.

Lastly Groth† has adopted the formula of Jannasch [SiO₄]₂ · BO₂ · R'₉, but interprets it as follows:

* Bulletin of the U. S. Geological Survey, No. 125, p. 56.

† Tabellarische Uebersicht der Mineralien, 4te Auflage, 1898, 117.



That the univalent radical (AlO) can replace R' does not appear in the original article of Jannasch, and it makes a decided difference whether three R's are replaced by one atom of Al or by three [AlO] radicals. The latter assumption implies a basic character which tourmaline does not possess.

We have thus reviewed the work already done in order to show the difficulties which this problem has presented. It is, however, interesting to note how closely different investigators come to one type of acid from which all varieties of tourmaline are derived. For the sake of comparison these acids have been reduced to four silicon atoms, and are given below, both as borosilicic acids and with the boron replaced by hydrogen.

Rammelsberg	$\left\{ \begin{array}{ll} \text{H}_{18}\text{B}_2\text{Si}_4\text{O}_{20} & \text{or } \text{H}_{24}\text{Si}_4\text{O}_{20} = \text{H}_6\text{SiO}_6 \\ \text{H}_{18.66}\text{B}_{1.77}\text{Si}_4\text{O}_{20} & \text{or } \text{H}_{24}\text{Si}_4\text{O}_{20} \end{array} \right.$
Riggs	$\left\{ \begin{array}{ll} \text{H}_{18}\text{B}_2\text{Si}_4\text{O}_{20} & \text{or } \text{H}_{24}\text{Si}_4\text{O}_{20} \\ \text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{20} & \text{or } \text{H}_{26}\text{Si}_4\text{O}_{20} \text{ (Irrational)} \\ \text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{21} & \text{or } \text{H}_{26}\text{Si}_4\text{O}_{21} \\ \text{H}_{19.33}\text{B}_2\text{Si}_4\text{O}_{20.66} & \text{or } \text{H}_{25.33}\text{Si}_4\text{O}_{20.66} \end{array} \right.$
Jannasch and Kalb	$\left\{ \begin{array}{ll} \text{H}_{18}\text{B}_2\text{Si}_4\text{O}_{20} & \text{or } \text{H}_{24}\text{Si}_4\text{O}_{20} \\ \text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{21} & \text{or } \text{H}_{26}\text{Si}_4\text{O}_{21} \end{array} \right.$
Wülfing	$\text{H}_{20}\text{B}_4\text{Si}_4\text{O}_{21} \quad \text{or } \text{H}_{26}\text{Si}_4\text{O}_{21}$
Goldschmidt	$\text{H}_{25.8}\text{Si}_4\text{O}_{20.9}$
Rheineck	$\left\{ \begin{array}{ll} \text{H}_{19.0}\text{B}_{1.9}\text{Si}_4\text{O}_{20.6} & \text{or } \text{H}_{24.7}\text{Si}_4\text{O}_{20.6} \text{ (Irrational)} \\ \text{H}_{18.9}\text{B}_{1.9}\text{Si}_2\text{O}_{20.3} & \text{or } \text{H}_{24.6}\text{Si}_4\text{O}_{20.3} \text{ etc.} \end{array} \right.$
Clarke	$\text{H}_{19.33}\text{B}_2\text{Si}_4\text{O}_{20.66} \quad \text{or } \text{H}_{25.33}\text{Si}_4\text{O}_{20.66}$

Method of analysis. — The present investigation was undertaken with the expectation that for the solution of the problem in hand it would probably not be necessary to make a long

series of analyses but rather *exceedingly accurate* analyses of a few carefully selected types of tourmaline. We therefore prefaced our work by a careful study of those features of the tourmaline analysis, which have proved most difficult. The method proposed by Gooch* of distilling off the boron with methyl alcohol and weighing it as calcium borate is very exact, but its application to an insoluble silicate, especially one containing fluorine, needed careful study. Mixtures were accordingly made of silicates to which weighed quantities of borax and fluorite were added and the following conditions were determined, which yielded the most accurate boron determinations. The mineral was fused with from four to five parts of sodium carbonate, the fusion extracted with water, and, without filtering, an excess of ammonium carbonate was added. The insoluble residue and the precipitate were filtered off, the filtrate concentrated, acidified slightly with nitric acid and distilled with methyl alcohol. The residue from the sodium carbonate fusion, together with the precipitate produced by the ammonium carbonate, was fused again with sodium carbonate, treated with water, filtered and distilled with methyl alcohol after acidifying with nitric acid. About one half of one per cent of boric oxide was obtained from the second treatment, and in no case did we succeed in obtaining an exact determination of the boric oxide without repeating the fusion. The weighed mixture of calcium borate and oxide was in all cases found to contain a small amount of fluorine. It was therefore dissolved in hydrochloric acid, and part of the lime together with calcium fluoride was precipitated with sodium carbonate. The precipitate was ignited, treated with acetic acid and the resulting calcium fluoride weighed. The amount of fluorine thus found never amounted to over 0.20 per cent.

Fluorine was determined by the modified Berzelius method described by Penfield and Minor.†

Water was determined by fusing the mineral with sodium carbonate in a combustion tube and collecting the water in a

* Amer. Chem. Jour., ix. p. 23.

† Page 232.

weighed tube containing sulphuric acid, a method which has been thoroughly tested and is known to give reliable results.*

For the determination of the bases the mineral was decomposed by fusion with sodium carbonate and the silica separated as usual. It was found by experiment that the amount of silica volatilized by the small amount of fluorine in the mineral could practically be neglected. In one variety of tourmaline two determinations of silica made by the Berzelius method of fusing the mineral and a weighed amount of silica with sodium carbonate, and separating the silica with ammonium carbonate and an ammoniacal solution of zinc oxide, gave 36.69 and 36.76 per cent, while determinations by the ordinary method gave 36.75 and 36.73 per cent. A similar conclusion, that when the amount of fluorine is small it is not necessary to separate the silica by the Berzelius method, was also reached by Riggs.

The filtrate from the silica was evaporated to dryness, moistened with hydrochloric acid and repeatedly evaporated with methyl alcohol to remove all possibilities of boric oxide being precipitated with the bases and thus increasing their weight.

For the determination of the alkalis the Smith fusion was employed and, after removal of ammonium salts, the residue was treated with acid and methyl alcohol and evaporated to remove any borate that might possibly be present. Lithium was separated by the Gooch method of boiling with amyl alcohol,† and was finally weighed as sulphate.

It was proved by careful qualitative tests‡ that the iron was ferrous, and that, at the most, not more than traces of ferric iron could be present. This statement holds good not only for the varieties analyzed, but for all the varieties of black tourmaline which were accessible to us.

Selection and preparation of material. — One of the varieties selected for analysis was the white or colorless tourmaline from De Kalb, St. Lawrence Co., New York. This was chosen

* Amer. Jour. Sci., 1894, vol. 48, p. 31.

† Amer. Chem. Jour., ix, p. 33.

‡ Amer. Jour. Sci., 1899, vol. 7, p. 124.

because according to the analysis of Riggs it represented almost the extreme type of a magnesia tourmaline, and, containing almost no iron, there could be no appreciable error from a failure to estimate that constituent correctly. The material was derived in part from a specimen in the Brush Collection and in part from specimens collected by one of us (Penfield) while connected with the U. S. Geological Survey. The clear, colorless, glassy material was most carefully selected with the aid of a lens, ground and sifted to a uniform grain, and suspended in methylen iodide. The specific gravity was uniform, and the portion used for the analysis floated at 3.065 and sank at 3.033. As an additional precaution the grains were treated with a mixture of hydrochloric and hydrofluoric acids, which have almost no action even on finely pulverized tourmaline, in order to remove any possible traces of adhering calcite, tremolite or pyroxene, although these were not seen nor believed to be present. It may be stated concerning the final product that probably it was as pure as it is possible to get a mineral substance.

Another variety selected for analysis was from the feldspar quarries at Haddam Neck on the Connecticut River. Wonderful tourmalines have recently been obtained from this locality, and they are already well known to most collectors. We are indebted for our supply of material to Mr. Ernest Schernikow of New York, who generously placed at our disposal an almost unlimited supply of crystals of gem quality. We selected small prisms, 2 to 4 mm. in diameter, of a uniform rather pale green color. They were of ideal purity, perfectly transparent and without flaws. Any traces of foreign material that might possibly be adhering to their outer surfaces were removed by treating them for a considerable time with hydrofluoric acid. The specific gravity, taken with the chemical balance, was found to be 3.089.

We were prepared to extend our investigation by analyzing other varieties, but having completed the above mentioned two and finding that the results corresponded with those of other investigators, it was decided that the data which would

be derived from further analyses would probably add very little to the knowledge which we already possess.

The results of the analyses are as follows:

COLORLESS TOURMALINE, DE KALB, N. Y.

	I.	II.	Average.			Riggs.
SiO ₂	36.69	36.76	$36.72 \div 60 =$	0.612	4.00	36.88
TiO ₂	0.06	0.05	0.05	...	...	0.12
B ₂ O ₃	10.86	10.77	$10.81 \div 70 =$	0.154	1.01	10.58
Al ₂ O ₃	29.75	29.61	$29.68 \div 17 = 1.741$	3.042	19.90	28.87
FeO	0.23	0.21	$0.22 \div 36 = 0.006$			0.52
MgO	14.91	14.92	$14.92 \div 20 = 0.746$			14.53
CaO	3.47	3.50	$3.49 \div 28 = 0.125$			3.70
Na ₂ O	1.29	1.23	$1.26 \div 31 = 0.040$			1.39
K ₂ O	0.07	0.03	$0.05 \div 47 = 0.002$			0.18
H ₂ O	2.98	...	$2.98 \div 9 = 0.331$	}		3.56
F	0.92	0.95	$0.93 \div 19 = 0.049$			0.50
			101.11			100.83
O equivalent to F			0.39			0.21
			100.72			100.62

GREEN TOURMALINE, HADDAM NECK, CONN.

	I.	II.	Average.			Brazil. Riggs.
SiO ₂	36.87	37.05	$36.96 \div 60 =$	0.616	4.00	37.39
TiO ₂	0.03	0.03	0.03	...	...	?
B ₂ O ₃	11.09	10.92	$11.00 \div 70 =$	0.157	1.02	10.29
Al ₂ O ₃	39.53	39.59	$39.56 \div 17 = 2.327$	3.078	19.98	39.65
FeO	2.12	2.15	$2.14 \div 36 = 0.059$			*2.42
MnO	1.96	2.04	$2.00 \div 35.5 = 0.056$			1.47
MgO	0.15	0.15	$0.15 \div 20 = 0.008$			none
CaO	1.32	1.25	$1.28 \div 28 = 0.046$			0.49
Na ₂ O	2.13	2.06	$2.10 \div 31 = 0.068$			†2.67
Li ₂ O	1.65	1.63	$1.64 \div 15 = 0.110$	}		1.71
H ₂ O	3.14	3.06	$3.10 \div 9 = 0.344$			3.63
F	1.09	1.17	$1.13 \div 19 = 0.060$	}		0.32
			101.09			100.04
O equivalent to F			0.48			0.13
			100.61			99.91

On treating the analyses according to the customary method of deriving a formula (dividing each constituent by its molecular weight and finding the ratio of the quotients) it was

* Includes 0.15 per cent Fe₂O₃.

† Includes 0.25 per cent K₂O.

found that although the SiO_2 and B_2O_3 were present in the proportion of 4 : 1, no definite relation could be detected between the silica, the different kinds of oxides, and the water. It was decided, therefore, to determine the relative number of hydrogen atoms equivalent to the metals and thus learn the acid from which tourmaline is derived. This was readily accomplished by dividing the constituents by appropriate fractions of their molecular weights; for example, since the aluminium atoms in Al_2O_3 replace six hydrogens, the quantity of Al_2O_3 was divided by one sixth of its molecular weight, the FeO by one half of its molecular weight, etc. Since fluorine is regarded as playing the same role as hydroxyl, its ratio was added directly to that of the hydrogen. The result of this treatment is very satisfactory. The first analysis gives the ratio of $\text{SiO}_2 : \text{B}_2\text{O}_3 : \text{H} = 4 : 1 : 19.90$, and the second 4 : 1.02 : 19.98. Both ratios approximate so closely to 4 : 1 : 20 that there can be no reasonable doubt that the acid from which these tourmalines are derived is $\text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{21}$. This formula may seem at first somewhat complex, but it is not especially so for a boro-silicic acid. It cannot be simplified by division, and it is based upon the very best kind of evidence, namely, the close approximation to rational numbers of the two ratios, which are derived from widely separated types of tourmaline.

Before discussing the possible constitution of this acid, it will be shown to what extent the analyses of other investigators confirm the results obtained by us.

Review of the Analyses of Riggs.—Twenty analyses of American tourmalines were made by Riggs, and the ratios derived from them furnish the very best evidence of the accuracy of his results. The ratios are given on page 312. The average of the ratios is 4 : 0.95 : 19.88, or a very close approximation to 4 : 1 : 20, which indicates that tourmaline is derived from the acid $\text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{21}$. It is pointed out by Riggs that "the boric acid found invariably falls short of the theory." This is generally, though not always, the case, and it is presumed that this slight defect in the analyses is

No.*	SiO ₂ :	B ₂ O ₃ :	Total hydrogen.	No.	SiO ₂ :	B ₂ O ₃ :	Total hydrogen.
36.	4 :	0.90 :	20.2	46.	4 :	0.96 :	20.2
37.	4 :	0.93 :	20.5	47.	4 :	0.98 :	20.08
38.	4 :	0.92 :	19.5	48.	4 :	1.01 :	20.06
39.	4 :	0.94 :	19.7	49.	4 :	1.01 :	20.12
40.	4 :	0.96 :	19.3	50.	4 :	0.98 :	19.2
41.	4 :	0.92 :	19.7	51.	4 :	0.91 :	19.6
42.	4 :	0.97 :	19.8	52.	4 :	0.94 :	20.11
43.	4 :	0.94 :	20.03	53.	4 :	0.97 :	18.9
44.	4 :	0.88 :	20.2	54.	4 :	0.98 :	19.8
45.	4 :	0.95 :	20.03	55.	4 :	1.01 :	20.6

due to the fact that it is not always possible to obtain a correct determination of boric oxide by the Gooch method without a second fusion of the silicate with sodium carbonate, which Riggs does not mention having made. It is not indicated by the ratios that these analyses "give as a general tourmaline formula the simple boro-orthosilicate $R_3BO_2SiO_4$ " suggested by Riggs. The nearest approach to this is analysis No. 53, in which the ratio of SiO₂ to the total hydrogen is 4 : 18.9. The ratios with few exceptions show a very close approximation to the rational numbers 4 : 1 : 20. In eleven cases the numbers for the hydrogen ratios vary between the narrow limits 19.8 and 20.2. How exact the analyses must be in order to yield such ratios may be best understood when it is known that a difference of one-half of 1 per cent in the estimation of either silica or water would change the numbers of the hydrogen ratio ± 0.27 in the one case and ± 0.38 in the other. If the silica were one-half of one per cent high and the water correspondingly low, the effect upon the ratio would be to change it from 4 : 1 : 20 to 4 : 0.99 : 19.35. The evidence is therefore convincing that, with the exception of analysis No. 53 (brown tourmaline from Gouverneur, N. Y.), the analyses of Riggs are very exact, and also that

* The numbers correspond to those given on page 555 of the Sixth Edition of Dana's Mineralogy, where the analyses of Riggs are tabulated. The same holds true for other analyses, cited on pp. 313, 314, and 315.

the material he analyzed was very pure.* Leaving out of consideration this one analysis, which may be considered as either defective or made upon impure material, the average of the ratios of Riggs's analyses becomes 4 : 0.95 : 19.91.

The analyses of Riggs were very severely criticized by Rammelsberg, who characterized tourmaline analysis as "*kein Thema für Anfänger*," but in the light of our present investigation we find the results very accurate, and it may justly be said that we are indebted to Riggs for the best series of tourmaline analyses that has ever been made. In fact, our conclusions regarding the composition of the mineral might readily have been deduced from his results alone.

Review of the Analyses of Jannasch and Kalb. — Nine analyses were made, from which the following ratios have been calculated:

No. †	SiO ₂ :	B ₂ O ₃ :	Total hydrogen.	No.	SiO ₂ :	B ₂ O ₃ :	Total hydrogen.
56.	4 :	0.96 :	19.7	61.	4 :	0.95 :	20.2
57.	4 :	0.99 :	19.8	62.	4 :	0.80 :	20.00
58.	4 :	0.95 :	20.4	63.	4 :	0.98 :	19.7
59.	4 :	0.92 :	18.8	64.	4 :	0.84 :	20.01
60.	4 :	0.88 :	20.4	Average	4 :	0.92 :	19.9

These analyses, like those of Riggs, bear every evidence of having been made with great precision, and the ratios, with the single exception of No. 59, approximate closely to 4 : 1 : 20, thus furnishing additional evidence that the acid from which all tourmalines are derived is H₂₀B₂Si₄O₂₁. The analyses do not indicate the general formula R₉ · BO₂ · 2SiO₄, proposed by Jannasch and Kalb. Their boric oxide determinations are in all cases a trifle too low for the theory, but it is believed that the reason for this is to be sought in imperfections of the

* In a personal communication from Professor Riggs the following statement is made concerning the quality of the material investigated by him: "The material analyzed was of excellent quality, selected with great care. The colorless, pink and light green varieties were transparent, gem-like crystals, and the material of the rose-colored, brown and black varieties was, in my opinion, equally pure." Dated, Hartford, January 4th, 1899.

† See p. 312.

method * for determining this constituent in a complex silicate. The analyses are excellent, and they rank with those of Riggs, among the best analyses of tourmaline that have been made. From our own experience, however, it is very questionable whether tourmaline contains so much ferric iron as recorded in some of these analyses (2.90 to 6.68 per cent).

The Analyses of Scharizer. — The ratios of the three analyses are as follows:

No. †	SiO ₂	:	B ₂ O ₃	:	Total hydrogen.
65.	4	:	0.70	:	20.9
66.	4	:	0.76	:	21.0
67.	4	:	0.74	:	20.2

By comparing these ratios with the ones which have been previously considered, it would seem that there are good grounds for believing that in these analyses the B₂O₃ determinations are too low, and that the bases have not been determined with extreme accuracy. The ratios of SiO₂ to the total hydrogen atoms in the main substantiate the formula H₂₀B₂Si₄O₂₁.

Analyses from Miscellaneous Sources. — In looking over the literature a number of analyses have been found which need to be recorded. They have been made partly for the purpose of identifying the mineral and partly for the purpose of determining the character of the tourmaline from special localities, but none of them have been made for the special purpose of determining the chemical composition of the species. It seems sufficient to give the ratios only, page 315.

As indicated by the variations in the ratios, the analysts apparently have not had sufficient experience to enable them to deal successfully with such a difficult problem as the tourmaline analysis. The average of the ratios, however, approximates to 4 : 1 : 20 and thus substantiates our formula.

Titanium in tourmaline. — Titanium seems to have been overlooked in the earlier analyses of tourmaline, but is reported in several of the analyses of Riggs, Jannasch and Kalb, and others. The quantity, however, has always been found to be

* Bodewig, Zeitschr. für Kryst., viii, p. 211, 1883.

† See p. 312.

No. *	Locality.	Analyst.	SiO ₂ :	B ₂ O ₃	Total : hydrogen.
69.	Mt. Bischoff	Sommerland	4	: 0.98	: 18.5
70.	Campolongo	Engelmann	4	: 0.82	: 17.4
71.	Sysersk, Urals	Cossa and Arzruni	4	: 0.89	: 18.8
72.	Montgomery Co., Md.	Chatard	4	: 0.84	: 20.4
73.	Nevada Co., Cal.	Melville	4	: . . .	: 20.8
74.	Tamaya, Chili	Schwarz	4	: 1.02	: 19.1
75.	Straschin, Bohemia . .	Weisner	4	: 1.10	: 19.4
76.	Urulza, Siberia	Stehusseff	4	: 0.85	: 19.0
77.	Kolar, India	Chapman Jones . .	4	: 0.87	: 19.1
		Average	4	: 0.92	: 19.2

small, amounting to over one per cent (reckoned as TiO₂) in only four of the analyses and to over 0.6 per cent in but two others. It has not been taken into consideration in making the foregoing calculations, partly because it would exert no appreciable influence on the final result, but chiefly because it is uncertain whether the titanium in this mineral plays the part of a tetravalent element replacing silicon, or of a trivalent element replacing aluminium. Although it may not be possible with the data now at hand to definitely settle this question, still the analyses furnish some evidence that the element should be regarded as trivalent. This result has been reached by considering titanium both as TiO₂ replacing SiO₂ and as Ti₂O₃, replacing Al₂O₃, and comparing the ratios derived from the four analyses in which the TiO₂ has been recorded as over 1 per cent. The results are given on page 316.

In these four cases it will be observed that the calculations give the closest approximation to the normal tourmaline ratio when the titanium is regarded as Ti₂O₃. Moreover when the titanium is regarded as TiO₂ the departure from the normal ratio is so great that it does not seem probable that this is due wholly to defects in the analyses. Some very careful and

* 69, 70, 71, and 72 quoted in Dana's Mineralogy; 73, Bull. U. S. Geolog. Survey, No. 90, p. 39; 74, Zeitschr. deutsch. Geol. Gesell., xxxix, p. 238; 75, Min. u. Petr. Mitth., ix, p. 410; 76, Zeitschr. Kryst., xx, p. 93; 77 Min. Mag., xi, p. 61.

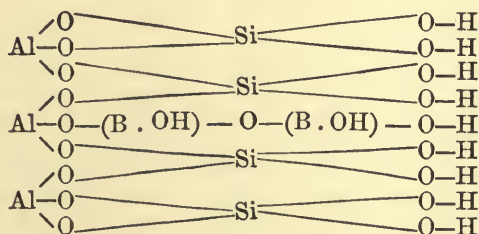
No.	Locality.	Premises.	Total	
			SiO ₂	B ₂ O ₃ hydrogen.
51. Monroe, Conn., Riggs		TiO ₂ 1.61 per cent . .	4 : 0.88	18.9
		Neglecting titanium . .	4 : 0.91	19.6
		Ti ₂ O ₃ 1.45 per cent . .	4 : 0.91	19.97
53. Gouverneur, N. Y., Riggs		TiO ₂ 1.19 per cent . .	4 : 0.95	18.5
		Neglecting titanium . .	4 : 0.97	18.9
		Ti ₂ O ₃ 1.07 per cent . .	4 : 0.97	19.2
56. Snarum, Jannasch and Kalb		TiO ₂ 1.10 per cent . .	4 : 0.93	19.1
		Neglecting titanium . .	4 : 0.96	19.7
		Ti ₂ O ₃ 0.99 per cent . .	4 : 0.96	19.9
59. Tamatawe, Jannasch and Kalb		TiO ₂ 1.22 per cent . .	4 : 0.90	18.4
		Neglecting titanium . .	4 : 0.92	18.8
		Ti ₂ O ₃ 1.10 per cent . .	4 : 0.92	19.1

exact analytical work must be done, however, in order to decide this question definitely.

Constitution of tourmaline.—The evidence thus far presented may be considered as convincing that all tourmalines are derivatives of a complex borosilicic acid $H_{20}B_2Si_4O_{21}$, and it is believed that further analyses will not alter this result, although they may furnish important data concerning the constitution of the acid. All of the hydrogen atoms of this acid in tourmaline are not replaced by metals, for the different varieties have always been found to contain water, which indicates the presence of hydroxyl. The ratio of the silica to the hydrogen derived from water (hydroxyl) plus the fluorine is not constant, but varies in Riggs's and our analyses from 4 : 3.14 (pale green tourmaline from Auburn, Maine) to 4 : 2.48 (colorless tourmaline from De Kalb). In all of the analyses in which water has been estimated directly, a sufficient quantity has been obtained to yield two hydroxyls in the formula; in only a few cases has the amount been sufficient to yield three hydroxyls. We are thus led to believe in the existence of two hydroxyls in all tourmalines, and it seems natural to associate them with the two boron atoms. The acid consequently becomes $H_{18}(BOH)_2Si_4O_{19}$. The small amount of fluorine which is found in many varieties of tourmaline presumably plays the same rôle as hydroxyl, or is

isomorphous with it, as in the case of topaz, of chondrodite, and of other minerals containing fluorine and hydroxyl. The slight excess of hydrogen over and above the two hydroxyls may be regarded as basic hydrogen, which plays the rôle of a metal. Such a relation is known to exist in complex mineral compounds.*

One of the peculiar features of tourmaline is that varying proportions of metals of different valences and of essentially different character replace the hydrogens of the acid $H_{18}(BOH)_2Si_4O_{19}$. In all cases thus far examined aluminium predominates and is present in sufficient quantity to replace more than half the hydrogens. From this it has been inferred that an aluminium-borosilicic acid $H_9Al_3(BOH)_2Si_4O_{19}$ is characteristic for all varieties of tourmaline. The constitution of this acid may be expressed graphically as follows:



It would seem that the mass effect of the complex radical $[Al_3(BOH)_2Si_4O_{19}]$, which has a valence of nine, is sufficiently pronounced to control or dominate all types of tourmaline. Thus it apparently makes no difference whether the nine hydrogens are replaced largely by aluminium and to a slight extent by alkalis; or largely by magnesium and to a slight extent by aluminium and alkalis; or to about an equal extent by aluminium, iron or magnesium and alkalis; the result in all cases is the mineral tourmaline, with its characteristic crystallization and its peculiar optical and electrical properties.

The following example (compare the ratio derived from the

* Amer. Jour. Sci., 1890, vol. 40, p. 396.

analysis of the green tourmaline from Haddam Neck, page 310) will illustrate the method of determining to what extent the nine hydrogens of the tourmaline acid, $\text{H}_9\text{Al}_3(\text{BOH})_2\text{Si}_4\text{O}_{19}$, are replaced by metals of different valences :

	Ratio. Total hydrogen equivalent, or 20 H.	2(OH,F). 18 H.	3 Al. 9 H.	
Al_2O_3	2.327	2.327	1.385	$0.942 \div 0.154 = 6.1 \text{ R}'''$
FeO	0.059	0.169	0.169	$0.169 \div 0.154 = 1.1 \text{ R}''$
MnO	0.056			
MgO	0.008			
CaO	0.046			
Na_2O	0.068	0.178	0.178	$0.178 \div 0.154 = 1.2 \text{ R}'$
Li_2O	0.110			
H_2O	0.344	0.404	0.308	$0.096 \div 0.154 = 0.6 \text{ H.}$
F	0.060			
	<u>20)3.078</u>	<u>2)2.770</u>	<u>9)1.385</u>	<u>9.0</u>
	0.154	1.385	0.154	

From the ratio of the total hydrogen equivalent, $\frac{2}{20}$ (representing two hydroxyls) are deducted. The remainder, 18 H, is divided by two, thus determining the ratio of the nine H's replaced by Al_3 in the formula. The excess of the aluminium or trivalent metal ratio, R''' , together with the ratios of the bivalent metals, R'' , the alkali metals R' and the excess of hydrogen, H, represent nine H's, which are divided among the different constituents. Thus in the green tourmaline from Haddam Neck 6.1 hydrogens are replaced by Al (R'''), 1.1 by R'' , 1.2 by R' and there remains 0.6 excess of basic hydrogen.

The analyses of Riggs, Jannasch and Kalb, Scharizer and Chatard, given on page 555 of Dana's Mineralogy, together with our own analyses, practically include all varieties of tourmaline which have thus far been investigated, and in the following table are given the results of applying the foregoing method of calculation to them :

It will be observed that the extent to which the nine hydrogens of the acid $\text{H}_9\text{Al}_2(\text{BOH})_2\text{Si}_4\text{O}_{19}$ are replaced by metals, is very variable. The trivalent metal, R''' , is chiefly aluminium, and the extent to which the hydrogens are replaced by it

	No.	Locality.	Color.	Analyst.	R'''	R''	R'	H
Lithia Tourmalines.	1	Minas Geraes, Brazil . .	Pale pink .	Riggs, 37	6.7	0.3	1.2	0.8
	2	Rumford, Me.	Rose	Riggs, 36	6.5	0.2	1.2	1.1
	3	Brazil	Green	Jann. & Kalb, 64 .	6.3	1.1	0.9	0.7
	4	Auburn, Me.	Colorless .	Riggs, 38	6.2	0.6	1.1	1.1
	5	Minas Geraes, Brazil . .	Pale green .	Riggs, 39	6.2	0.8	1.3	0.7
	6	Schüttenhofen, Bohemia	Red	Scharizer, 67 . .	6.1	0.3	1.3	1.3
	7	Haddam Neck, Conn. . .	Pale green .	Authors	6.1	1.1	1.2	0.6
	8	Barra do Perahy, Brazil .	Green	Jann. & Kalb, 63 .	6.0	1.1	1.4	0.5
	9	Rumford, Me.	Dark green .	Riggs, 42	6.0	1.3	1.1	0.6
	10	Minas Geraes, Brazil . .	Olive green .	Riggs, 41	5.9	1.1	1.3	0.7
	11	Auburn, Me.	Light green .	Riggs, 40	5.7	0.9	1.2	1.2
	12	Schüttenhofen, Bohemia	Blue green .	Scharizer, 66 . .	5.5	1.2	1.2	1.1
	13	Auburn, Me.	Dark green .	Riggs, 43	5.3	1.5	1.1	1.1
Iron Tourmalines, No. 21 excepted.	14	Buckworth, Australia .	Black	Jann. & Kalb, 62 .	4.7	2.9	0.7	0.7
	15	Paris, Me.	Black	Riggs, 44	4.7	3.0	0.5	0.8
	16	Auburn, Me.	Black	Riggs, 45	4.7	3.1	0.5	0.7
	17	Alabashka, Russia . . .	Black	Jann. & Kalb, 57 .	4.7	3.2	0.5	0.6
	18	Mursinka, Russia. . . .	Black	Jann. & Kalb, 60 .	4.7	3.2	0.7	0.4
	19	Schüttenhofen, Bohemia	Blue-black .	Scharizer, 65 . .	4.5	3.0	0.5	1.0
	20	Piedra Blanca.	Black	Jann. & Kalb, 58 .	4.4	3.2	0.6	0.8
	21	Montgomery Co., Md. .	Green (Cr) .	Chatard, 72 . . .	4.4	3.4	0.5	0.7
	22	Minas Geraes, Brazil . .	Black	Riggs, 46	4.3	3.5	0.5	0.7
	23	Stony Point, N. C. . . .	Black	Riggs, 48	4.2	3.6	0.5	0.7
Magnesia-Iron Tourmalines.	24	Oláhpian.	Black	Jann. & Kalb, 61 .	4.0	4.1	0.5	0.4
	25	Hamatawe	Black	Jann. & Kalb, 59 .	3.8	4.6	0.5	0.1
	26	Haddam, Conn.	Black	Riggs, 47	3.7	4.0	0.5	0.8
	27	Snarum, Norway	Black	Jann. & Kalb, 56 .	3.7	4.4	0.7	0.2
	28	Orford, N. H.	Dark brown .	Riggs, 52	3.6	4.1	0.6	0.7
	29	Monroe, Conn.	Dark brown .	Riggs, 51	3.4	4.1	0.7	0.8
	30	Nantic Gulf, Baffin's Ld.	Black	Riggs, 49	3.1	4.7	0.5	0.7
	31	DeKalb, N. Y.	Colorless . .	Authors	2.5	5.7	0.3	0.5
	32	DeKalb, N. Y.	Colorless . .	Riggs, 54	2.2	5.7	0.4	0.7
	33	Gouverneur, N. Y. . . .	Brown	Riggs, 53	2.2	5.6	0.4	0.8
Mg & Fe.	34	Hamburg, N. J.	Brown	Riggs, 55	2.0	6.2	0.2	0.6
	35	Pierrepont, N. Y. . . .	Black	Riggs, 50	1.6	6.3	0.4	0.7

ranges from 6.7 to 1.6. The bivalent metals represented by R'' are chiefly iron and magnesium, and the extent to which the hydrogens are replaced by them ranges from 0.3 to 6.3. In general R'' and R''' are reciprocal. There is always some hydrogen replaced by the alkali metals R', and some basic hydrogen. The results are arranged in the table according to a decrease in the replacement of the hydrogens by R''', and according to this arrangement the different varieties of tourmaline fall into natural groups.

The first 13 examples are characterized by containing an appreciable quantity of lithium, while in the others none, or

not more than traces of this element have been found; these may therefore be designated as *Lithia Tourmalines*, which form a natural group. In this group R' is higher than in other varieties, while H is somewhat higher than the general average; R''' is very high and R'' correspondingly low. This variety of tourmaline has its particular mode of occurrence, being found in pegmatite veins associated with quartz, albite, microcline, orthoclase, muscovite and lepidolite. The material is generally delicately colored and often transparent and of gem-like quality. It is difficultly fusible when heated before the blowpipe, fusibility = $5-5\frac{1}{2}$.

At the opposite extreme, 31-34, are varieties which may be designated as *Magnesia Tourmalines*. In these R'' , which is chiefly magnesium, is very high and R''' correspondingly low, while R' reaches its lowest limit, 0.2 to 0.4. These varieties are light-colored and at times of gem-like quality. They are easily fusible before the blowpipe, fusibility = 3. With these No. 35 should be associated, for it differs only in containing considerable iron which is isomorphous with the magnesium, hence the color of this tourmaline is black. The last five are alike in their mode of occurrence. They have probably been formed in limestones containing magnesium by the contact action of intruded igneous masses during the pneumatolitic period, when such masses were giving off heated aqueous vapors containing boracic acid and fluorine compounds. They are found in coarse crystalline limestone, associated with graphite, phlogopite, pyroxene, amphibole, scapolite and apatite. Contact metamorphisms of this nature have recently been described by Lacroix.*

The intermediate varieties (Nos. 14 to 30) with the exception of No. 21 are black or dark brown, owing to the presence of iron. These are the ordinary tourmalines found in granites, gneisses and schists, and sometimes in pegmatite veins intimately associated with lithia tourmaline, as at Auburn and Paris, Maine. They too have probably resulted from the

* Les Granites des Pyrénées et ses Phénomènes de Contact, Bull. Carte Géologique de France, No. 64, Tome x, p. 54, 1898.

mineralizing action of heated aqueous vapors containing boracic acid and fluorine compounds, given off during the pneumatolitic period of cooling igneous rocks. A contact metamorphism of this character, attended by the formation of tourmaline vein stone, has been very carefully described by Hawes.*

Nos. 14 to 22 (No. 21 excepted) are characterized by containing iron and only a little magnesia, hence they may be designated as *Iron Tourmalines*; Nos. 23 to 30 contain both magnesia and iron, and are hence designated as *Magnesia-Iron Tourmalines*. These two groups, however, grade into one another. The fusibility of these intermediate groups of tourmalines varies from 4.5 to 3, and decreases as the amount of iron and magnesia increase.

Although in this series of thirty-five analyses there are pronounced groups or types of tourmaline which may be recognized, nowhere in the series do the ratios of R''' , R'' , R' and H approximate so closely to rational numbers that a definite formula for any one type can be instituted. Riggs and Jannasch and Kalb, however, have given special formulas for different types of tourmaline (pages 301 and 303) based upon multiples of the acid $H_{18}(BOH)_2Si_4O_{18}$. Deducting from their formulas appropriate multiples of the aluminium-borosilicic radical $[Al_3(BOH)_2Si_4O_{18}]$, it is found that the nine variable hydrogens of the tourmaline acid are replaced by metals of different valences in the following proportions:

		R'''	R''	R'	H
I. Lithia tourmaline	{ Riggs	7.0	0.0	1.3	0.7
	{ Jann. and Kalb	6.0	1.4	1.3	0.3
II. Iron tourmaline	{ Riggs	5.0	2.6	0.7	0.7
	{ Jann. and Kalb	5.0	3.0	0.7	0.3
III. Iron-magnesia tour.	Jann. and Kalb	4.0	4.0	0.7	0.3

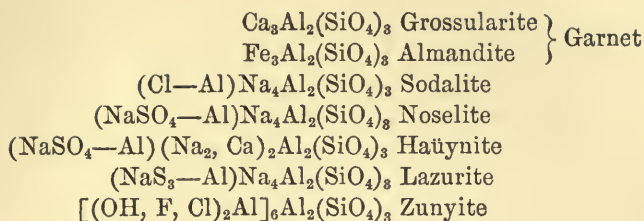
Concerning the formulas for lithia tourmaline, Riggs's corresponds closely to No. 1, and Jannasch and Kalb's to Nos. 7,

* The Albany Granite, New Hampshire, and its Contact Phenomena, see page 400.

8, 9, and 10 of our series (compare the table on p. 319), but neither of these complicated formulas furnishes a satisfactory expression for this type as a whole. Similar statements might be made concerning their formulas for iron tourmalines and for iron magnesia tourmalines. The endeavor to express the composition of tourmaline or of one of its types by a definite formula may be compared to the attempt to express the composition of the dark varieties of sphalerite by a formula. Thus $\text{Zn}_{11}\text{Fe}_4\text{S}_{15}$ would correspond to sphalerite containing about 50.5 per cent of zinc and 15.7 per cent of iron, but zinc and iron are isomorphous and can mutually replace one another in sphalerite, and a variety containing less iron would have to be expressed by a different formula. When, however, we understand the isomorphous relations existing between zinc and iron, and express the composition by RS , where $\text{R} = \text{Zn}$ and Fe , the composition becomes very much simplified.

In tourmaline we have an isomorphous relation of a very peculiar nature, for in the acid $\text{H}_9\text{Al}_3(\text{BOH})_2\text{Si}_4\text{O}_{19}$ the nine hydrogens may be replaced to a large extent either by the trivalent metal aluminium or by the bivalent metals magnesium and iron without any decided change in crystalline form. This leads to the consideration of a certain phase of isomorphism which, as it seems to us, has not been considered with sufficient care, namely, the *mass effect* of complex radicals in influencing or controlling crystallization. Thus in their simple salts we do not regard sodium and potassium as isomorphous with calcium, but in some complex silicates, zeolites for example, we recognize Na_2 and K_2 as isomorphous with, or at least capable of replacing, calcium, barium, and strontium. In some of the phosphates, dickinsonite and fillovite for example, we have sodium (Na_2) playing the same rôle as calcium, manganese, and iron in replacing the hydrogens of phosphoric acid. In the garnet-sodalite group we have minerals with isometric crystallization, to which the following formulas have been assigned: *

* Brögger and Bäckström, Zeitschr. für. Kryst., xviii, p. 209, 1890.



When it is taken into consideration that isometric crystallization is exceptional in the group of silicates, we are led to believe that the sexivalent radical $[\text{Al}_2(\text{SiO}_4)_3]$, by virtue of its *mass effect*, controls or dominates the crystallization of these minerals. Not only are they isometric, but, with the exception of zunyite, which is tetrahedral, they all crystallize commonly in dodecahedrons. In sodalite, noselite, and lazurite, such unlike constituents as chlorine, and the univalent sulphate and polysulphide radicals $(\text{NaSO}_4)'$ and $(\text{NaS}_3)'$ play the same part in the complex molecules. It is, moreover, probable that these unlike constituents are isomorphous in the sense that they can mutually replace one another, for Brögger and Bäckström have described homogeneous material containing the lazurite, häüynite and sodalite molecules, while appreciable quantities of chlorine are almost always found in noselite and häüynite, thus indicating the presence of the isomorphous sodalite molecule. It is to be expected that the larger and more complex the radical the more potent will be its *mass effect* in controlling or determining the crystal form. Thus in sodalite, noselite and häüynite the radical is very large, $[\text{R}'_4\text{Al}_2(\text{SiO}_4)_3]$, $\text{R}'_4 = \text{Na}_4$ or Ca_2 .

Tourmaline, it would seem, furnishes an example somewhat analogous to that presented by the garnet-sodalite group. In the acid $\text{H}_9\text{Al}_3(\text{BOH})_2\text{Si}_4\text{O}_{19}$ the *mass effect* of the complex radical $[\text{Al}_3(\text{BOH})_2\text{Si}_4\text{O}_{19}]$ is so great, or, the rôle played by the replacement of the nine hydrogens is so subordinate, that the bivalent elements, Fe, Mg, Mn, and Ca, and to a slight extent the alkalis, Li, Na, and K, can replace aluminium as isomorphous constituents. This conclusion in some respects is analogous to that reached by Rammelsberg, who stated in

1870 that all tourmalines were derived from an acid H_6SiO_6 , in which the six hydrogens were replaced in varying proportions by R'_6 , R''_3 , Al_2 and B_2 . Applying Rammelsberg's idea to the acid $H_{18}(BOH)_2Si_4O_{19}$, all varieties of tourmalines may be regarded as mixtures of the molecules

$R'_{18}(BOH)_2Si_4O_{19}$, $R' = Li, Na, K, \text{ and } H$

$R''_9(BOH)_2Si_4O_{19}$, $R'' = Fe, Mg, Mn, \text{ and } Ca$

$R'''_6(BOH)_2Si_4O_{19}$, $R''' = Al, Cr, \text{ and small amounts of } Fe \text{ and } Ti.$

It seems more logical and satisfactory, however, to consider all varieties of tourmalines as salts of the acid $H_2Al_3(BOH)_2Si_4O_{19}$, in which the complex aluminium-borosilicic acid radical $[Al_3(BOH)_2Si_4O_{19}]$ exerts a *mass effect* by virtue of which the remaining hydrogens may be replaced by metals of essentially different character without bringing about any pronounced change in crystalline form.

SOME NEW MINERALS FROM
THE ZINC MINES AT FRANKLIN, N. J., AND NOTE
CONCERNING THE CHEMICAL COMPO-
SITION OF GANOMALITE.

BY S. L. PENFIELD AND C. H. WARREN.

(From Amer. Jour. Sci., 1899, vol. 8, pp. 339-353.)

THE minerals to be described in the present paper came for the most part from the one-thousand-foot level of the Parker Shaft on North Mine Hill. Unfortunately at the time that they were brought to the surface, about two years ago, the fact that several new species were being mined was not known, and a quantity of material, which it is believed would prove to be very profitable hunting-ground for the new species was thrown upon the dump and subsequently covered up. Our attention has been called to these minerals at different times by Messrs. E. P. Hancock, of Burlington, N. J., J. J. McGovern, of Franklin, F. L. Nason, of West Haven, Conn., F. A. Canfield, of Dover, N. J., and W. M. Foote, of Philadelphia, Pa., while both of the writers at separate visits to the locality have been able to collect a few specimens. The new species were found in a somewhat limited area, and it is especially interesting to note the minerals which are associated with them, for they are very unusual even for Franklin, N. J., and would seem to indicate that peculiar conditions prevailed during the period when these minerals were being formed. The associated minerals are as follows: Native lead* and copper,† clinohedrite,‡ roeblingite,§ axinite in transparent yellow crystals, willemite

* Amer. Jour. Sci., 1898, vol. 4, p. 187.

† Proc. Am. Acad. of Arts and Sci., xxxiii, p. 429, 1898.

‡ This volume, p. 291.

§ Am. Jour. Sci., 1897, vol. 3, p. 413.

in exceptionally fine, transparent green crystals, vesuvianite, datolite, barite, garnet, brownish-black phlogopite, and a little franklinite. The presence of axinite and datolite containing boron and of phlogopite would seem to indicate that the minerals, part of them at least, have resulted from metamorphism brought about by the action of intruded igneous masses either during the pneumatolitic period when such masses were giving off heated aqueous vapors carrying boron and fluorine compounds, or during a period when heated waters, laden with mineralizing agents, were circulating through the deposit.

1. HANCOCKITE.

This mineral was found in considerable quantity both massive and in cellular masses of a brownish-red or maroon color, and attention has already been called to it as a new species by Penfield and Foote in their description of clinohedrite. Thus far it has been observed only in very small, lath-shaped crystals, the largest being not over 0.5 mm. in length and 0.15 mm. in diameter, and these generally are so intimately associated with garnet, axinite, and phlogopite that it was for a long time difficult to secure a specimen from which a sufficient quantity of the pure material could be obtained for the chemical analysis.



FIGURE 1.

The accompanying figure is a sketch of one of the crystals as seen under the microscope. The faces are striated parallel to the longer axis of the crystals, and they round into one another owing to oscillatory combinations. The terminal faces, necessarily very small, are vicinal, and it has thus far been impossible to find any crystal from which satisfactory measurements of the interfacial angles could be obtained. As may be seen from the figure the habit of the crystals is like that of epidote; that is, the prominent faces are parallel to the axis of symme-

try, and the crystals are terminated by two faces corresponding to the form $n(\bar{1}11)$ of epidote. On one of the crystals it was possible to obtain approximate measurements with the Fuess reflecting goniometer by using a strong illumination of the signal and the δ ocular. The measurements, given in the accompanying table, although not sufficiently accurate for establishing an axial ratio, indicate that the forms and angles of hancockite are similar to those of epidote.

	Hancockite, Approximate measurements.	Epidote.
$c \wedge e, 001 \wedge 101 =$	$36^{\circ} 15'$	$34^{\circ} 43'$
$e \wedge a, 101 \wedge 100 =$	$30^{\circ} 45'$	$29^{\circ} 54'$
$c \wedge r, 001 \wedge \bar{1}01 =$	63°	$63^{\circ} 42'$
$r \wedge a, \bar{1}01 \wedge \bar{1}00 =$	$55^{\circ} 30'$	$51^{\circ} 41'$
$n \wedge n, \bar{1}11 \wedge 11\bar{1} =$	67°	$70^{\circ} 29'$
$c \wedge n, 001 \wedge \bar{1}11 =$	77°	$75^{\circ} 11'$

Although the appearance of the mineral in the hand specimen varies from a dark to a light brownish-red, single crystals, as seen with a pocket lens, have a yellowish-brown color. Crystals like Figure 1, when examined with the polarizing microscope, exhibit distinct pelochroism, yellowish-brown for vibrations parallel to b , which corresponds to the crystallographic axis b , and somewhat variable for vibrations at right angles to this direction, being delicate rose color at the attached end and grading to pale, somewhat greenish-yellow at the terminated end. On some very small individuals the delicate rose color was observed throughout the whole length of the crystals. With crossed nicols the crystals show an extinction when their longer or symmetry axis is parallel to the plane of the polarizer. In convergent light something of the outer rings of the biaxial interference figure could be seen, accompanied by a dark bar, indicating plainly that the optical axes are in the symmetry plane. By rotating a crystal, when immersed in the potassium mercuric-iodide solution, the optical axes could be brought separately to the center of the field and their divergence $2V$ was found to be approximately 50° .

The luster of the hancockite crystals is vitreous, and the

hardness is about 6.5–7. Owing to the small size of the crystals and their intimate association with garnet, axinite and willemite, considerable difficulty was experienced in finding a specimen from which a sufficient quantity of pure material could be obtained for analysis. A specimen, however, finally came to us through Mr. Hancock, consisting of a cellular mass in which the walls and the drusy lining consisted chiefly of hancockite. By crushing this specimen, picking out the small fragments and examining them with a lens, it was possible to obtain the mineral almost absolutely free from the associated garnet and axinite, which could be distinguished by their lighter color. An attempt to separate the minerals by differences in their specific gravity was not successful. The specific gravity of the carefully selected material was found to be 4.030.

Concerning the method of analysis, the only points which need to be specially commented upon are the following: After separation of the silica, the lead was precipitated with hydrogen sulphide and subsequently converted into sulphate and weighed. The iron and alumina were separated from the bivalent metals by a basic acetate precipitation, reprecipitated by ammonia and weighed as oxides, the iron being estimated subsequently by means of potassium permanganate. The calcium and strontium were converted into nitrates and separated by means of amyl alcohol as directed by Browning.* Water was estimated by loss on ignition. Careful tests failed to reveal the presence of any ferrous iron. The deep color of the crystals at first suggested the idea that the mineral would be rich in manganese, which is by no means the case. The color, however, is probably due to the presence of some higher oxide of manganese which is known to impart an intense color to silicates and was estimated by the method described by Penfield.†

The results of the analysis by Warren are as follows:—

* Amer. Jour. Sci., 1892, vol. 43, p. 50.

† Ibid., 1893, vol. 46, p. 291.

Average. Ratio.					Partial Analysis.		
SiO ₂	30.99	...	30.99	0.516	SiO ₂	6.00	SiO ₂ 30.88
Al ₂ O ₃	17.89	...	17.89	0.173			Al ₂ O ₃ 17.99
Fe ₂ O ₃	12.30	12.37	12.33	0.077	} 0.259	R ₂ O ₃ 3.00	Fe ₂ O ₃ 12.96
Mn ₂ O ₃	1.38	...	1.38	0.009			...
PbO	18.47	18.59	18.53	0.083	} 0.367	RO 4.26	PbO 17.47
MnO	2.12	...	2.12	0.029			MnO 2.96
MgO	0.52	...	0.52	0.013			MgO 1.02
CaO	11.50	...	11.50	0.205			CaO } 15.33
SrO	3.89	...	3.89	0.037			SrO }
H ₂ O	1.62	...	1.62	0.090		H ₂ O 1.06	1.62
				100.77			
							100.23

The ratio of SiO₂ : R₂O₃ : RO : H₂O approximates closely to 6 : 3 : 4 : 1, which gives as the empirical formula H₂R''₄R'''₆Si₆O₂₆, or R''₂(R'''OH)R'''₂(SiO₄)₃. The general formula is that of epidote, but the material differs from any variety of that mineral previously described in having the bivalent metals lead and strontium isomorphous with calcium. Owing to its color and the presence of manganese sesquioxide the mineral is allied to piedmontite. It will be observed that the quantity of protoxide, RO, indicated by the analysis, is a trifle high, SiO₂ : RO being 6 : 4.26 instead of 6 : 4, as it should be to satisfy the epidote formula. The analyses, however, were made with very great care, and in the determination of the calcium and strontium the separated oxides were converted into sulphates and thus found to have the correct molecular weight. The partial analysis given was made on material taken from the same specimen as used for the other analysis, but the higher oxide of manganese was not determined and strontium was not separated from the calcium.

In its chemical as well as in its crystallographic relations, hancockite is a member of the epidote group of minerals, and should occupy a position next to piedmontite in a system of mineralogy. It is especially interesting on account of the considerable quantities of lead and strontium which it contains, elements thus far observed in combination with silicic acid in only a few rare mineral species.

Before the blowpipe, hancockite fuses with intumescence at

3 to a black, slightly magnetic globule. The globule becomes more strongly magnetic if heated on charcoal. With sodium carbonate on charcoal a coating of lead oxide is obtained. Reacts for manganese with the sodium carbonate bead in O. F. The mineral is insoluble in hydrochloric acid, but, like epidote, after fusion it dissolves and yields gelatinous silica upon evaporation. In the closed tube, at a high temperature, a little water is given off.

A considerable quantity of hancockite was taken from the mine at one time, and it is the most abundant of the new species described in this paper. It is named after Mr. E. P. Hancock of Burlington, N. J.

2. GLAUCOCHROITE.

This mineral was collected by S. L. Penfield in September, 1898, and was subsequently sent to New Haven for identification by Mr. W. M. Foote, who had collected several specimens of it earlier in the season. It occurs in prismatic crystals belonging to the orthorhombic system, and in columnar aggregates imbedded in a white matrix. The largest crystals thus far observed do not average over 2 mm. in greatest diameter, while the length of some of the columnar aggregates somewhat exceeds 10 mm.

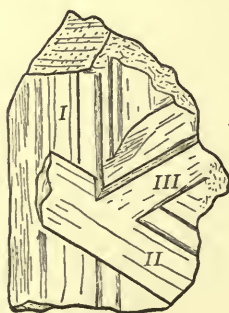


FIGURE 2.

Isolated crystals generally show the form of a prism $m(110)$, sometimes in combination with a second prism $s(120)$, and thus far all attempts to find a crystal with terminal faces have proved unsuccessful. A few penetration and contact twins have been observed, the twinning plane being the brachydome (011) , and the vertical axes of the individuals crossing at angles of about 60° and 120° . Figure 2 is an illustration of one of these penetration twins, drawn with the camera lucida as it appeared under the microscope. On the twin crystals the pinacoid $a(100)$ is generally

developed, although it was not observed on any of the simple crystals.

The prismatic faces, although bright, were vicinal, and consequently it was difficult to obtain reliable measurements of the prismatic angle. The average of a number of measurements of $m \wedge m$, $110 \wedge 1\bar{1}0$, was found to be $47^\circ 32'$, and this angle, taken as fundamental, agreed very closely with the values derived from the best reflections. As terminal planes were not observed, the angle between the vertical axes of two prisms in twin position was measured under the microscope and found to be 121° . Assuming the twinning plane to be the brachydome (011), the angle of $011 \wedge 0\bar{1}1$ was thus found to be 59° , which was taken as the second fundamental angle. From the foregoing fundamental angles the axial ratio has been calculated, and is given below, together with the axial ratios of monticellite and chrysolite, to which species glaucochroite is closely related, it being a manganese monticellite.

Glaucochroite, $a : b : c = 0.440 : 1 : 0.566$

Monticellite, $a : b : c = 0.431 : 1 : 0.576$

Chrysolite, $a : b : c = 0.466 : 1 : 0.586$

No reliable reflections could be obtained from the second prism $s(120)$. Approximate measurements are $120 \wedge 120 = 99^\circ$, calculated $97^\circ 16'$ and $m \wedge s$, $110 \wedge 120 = 17^\circ 21'$, calculated $17^\circ 36'$. A rather poor basal cleavage was detected, and measurements from this cleavage on to the prism faces gave angles of 90° .

The hardness is about 6. The specific gravity, taken with the pycnometer is 3.407. The fracture is conchoidal. The luster is vitreous and the color is a delicate bluish green, very similar to that of the aquamarine variety of beryl. Minute crystals are almost colorless, and on a few of the specimens there were small areas where the mineral exhibited a delicate pink color.

The optical orientation is $a = b$, $b = c$ and $c = a$. The plane of the optical axes is the base (001) and the acute bisectrix is normal to the brachypinacoid $b(010)$. The double refraction

is therefore negative. Prismatic crystals served as prisms for determining the indices of refraction $\alpha = 1.686$ and $\beta = 1.722$. These values were each derived from the mean of four independent measurements which showed considerable variation, owing to the vicinal character of the prismatic faces, but is believed that they represent a close approximation to the true values. On a section parallel to the pinacoid (010), which measured 0.5×1.5 mm., the divergence of the optical axes for yellow light, Na flame, was measured on the Fuess axial angle apparatus as follows: $2E = 121^\circ 30'$ and $2H$ in α -monobromnaphthalene $= 63^\circ 27'$. From these values $2V$, was found to be $60^\circ 53'$ and $60^\circ 49'$, respectively. The dispersion was marked $\rho > v$. From the values α , β and V , γ was calculated and found to be 1.735. The optical orientation, dispersion, and the character of the double refraction of glaucochroite are like those of monticellite as determined by Penfield and Forbes.* The indices of refraction for yellow light and the divergence of the optical axes, $2V$, of glaucochroite, monticellite and chrysolite are given below for comparison:

	α	β	γ	$\gamma - \alpha$	$2V$ over α
Glaucochroite,	1.686	1.722	1.735	0.049	$60^\circ 51'$
Monticellite,	1.6505	1.6616	1.6679	0.0174	$75^\circ 2'$
Chrysolite,†	1.661	1.678	1.697	0.036	$92^\circ 14'$

Very pure material for the chemical analysis was obtained by picking out the small prismatic crystals which separated readily from the matrix. The results of the analysis by Warren are as follows:

		Ratio.		Corrected analysis.	Theory for CaMnSiO_4 .
SiO_2	31.48	0.524	1.00	31.98	32.08
MnO	38.00	0.535	1.02	38.60	37.97
CaO	28.95	0.517	0.99	29.42	29.95
PbO	1.74			100.00	100.00
FeO	trace				
				100.17	

* Amer. Jour. Sci., 1896, vol. 50, p. 135.

† DesCloizeaux, Mémoires de l'Institut de France, T. xviii, p. 591.

Leaving out of consideration the small amount of PbO, which, owing to its high molecular weight, had only a slight effect upon the ratio, the ratio of $\text{SiO}_2 : \text{MnO} : \text{CaO} = 1.00 : 1.02 : 0.99$, or a very close approximation to $1 : 1 : 1$. The formula of glaucochroite is therefore CaMnSiO_4 , that of monticellite being CaMgSiO_4 . With the above analysis we have given the corrected analysis, after disregarding 1.74 per cent of PbO and calculating to 100 per cent, and also the theoretical composition corresponding to the formula CaMnSiO_4 . Glaucochroite takes therefore a place in the system of mineralogy next to monticellite as a member of the chrysolite group.

Glaucochroite fuses quietly before the blowpipe at about 3.5 to a brownish black globule, and imparts no color to the flame. The powdered mineral dissolves easily in hydrochloric acid, and the solution yields gelatinous silica upon evaporation. A little of the concentrated solution, when brought into contact with a drop of sulphuric acid on a watch glass, gives a precipitate of calcium sulphate. With either the borax or sodium carbonate beads a strong reaction for manganese is obtained.

So far as known, only a small amount of glaucochroite has been found. Its crystals occur imbedded in a white matrix, nasonite (see beyond), and intimately associated with brown garnet and yellow axinite. The name glaucochroite has been given to this species because of its color, from $\gamma\lambda\alpha\upsilon\kappa\omicron\varsigma = \text{blue-green}$ and $\chi\rho\omicron\iota\delta = \text{color}$.

3. NASONITE.

This material constitutes the matrix in which the crystals of glaucochroite are generally imbedded. It occurs massive, of white color, greasy to adamantine luster, hardness about 4, and hand specimens usually present a mottled or spotted appearance owing to numerous inclusions of yellow axinite and brown garnet, which are scattered rather uniformly through the massive nasonite. The material that has been examined consists of a few specimens collected by S. L. Penfield and some sent to us by Mr. W. M. Foote.

Thin sections when examined with the polarizing microscope

show that the material is crystalline, and that the masses consist of an intergrowth of crystal particles, some of which are several millimeters in diameter. No pronounced cleavages were observed under the microscope, and no crystal boundaries were detected which gave any clue to the system of crystallization. In convergent polarized light, however, certain sections gave a uniaxial interference figure, and, since the massive mineral broke up at times into rude rectangular blocks, it may be inferred that the crystallization is tetragonal and that the cleavage, which is poor, is prismatic and basal. The birefringence is rather strong, and the character of the double refraction is positive.

Material for the chemical analysis was obtained by crushing a large fragment and picking out the purest material by hand. The specific gravity was found to be 5.425. The results of the analysis by Warren are as follows:

	I.	II.	Average.	Ratio.		
SiO ₂	18.47	18.47	18.47	0.308		3.00
PbO	65.84	65.52	65.68	0.294	} 0.516	5.03
ZnO	0.84	0.80	0.82	0.010		
MnO	0.90	0.76	0.83	0.011		
FeO	0.10	. . .	0.10	0.001		
CaO	11.20	11.20	11.20	0.200	} 0.108	1.05
Cl	2.80	2.82	2.81	0.079		
H ₂ O	0.27	0.26	0.26 ÷ 9 = 0.029			
			100.17			
Oxygen equivalent of Cl			0.63			
			99.54			

The ratio of SiO₂ : (Pb + Zn + Mn + Fe + Ca)O : (Cl + OH) = 3.00 : 5.03 : 1.05 which approximates closely to 3 : 5 : 1, and, since two chlorine atoms are equivalent to one oxygen, this leads to the general formula R₁₀Cl₂Si₆O₂₁, R = Pb and Ca, and only traces of Zn, Mn, and Fe. Before discussing the general formula further, it may be stated that there were observed, intimately associated with the nasonite, a few particles of clinohedrite, H₂CaZnSiO₃, and it is probable therefore that the small percentage of zinc (0.82 per cent ZnO) was derived from

a slight admixture of this latter mineral. It seems therefore best to deduct from the foregoing analysis the ZnO , and sufficient amounts of SiO_2 , CaO and H_2O to form the clinohedrite molecule. The ratio then becomes $\text{SiO}_2 : (\text{Pb} + \text{Mn} + \text{Fe} + \text{Ca})\text{O} : (\text{Cl} + \text{OH}) = 0.298 : 0.496 : 0.098 = 3.00 : 5.01 : 0.99$, or almost exactly 3 : 5 : 1. Furthermore the ratio of $\text{SiO}_2 : \text{PbO} : (\text{Ca} + \text{Mn} + \text{Fe})\text{O} : (\text{Cl} + \text{OH}) = 0.298 : 0.294 : 0.202 : 0.098 = 3.00 : 2.97 : 2.04 : 0.99$ or, very closely, 3 : 3 : 2 : 1. Since Fe, Mn, and water (hydroxyl) are present only in very small amounts, they may practically be disregarded, and the empirical formula expressed as $\text{Pb}_6\text{Ca}_4\text{Cl}_2(\text{Si}_2\text{O}_7)_3$, or $\text{Pb}_4(\text{PbCl})_2\text{Ca}_4(\text{Si}_2\text{O}_7)_3$.

Below we have given the analysis, after deducting 2.16 per cent of clinohedrite, substituting for MnO and FeO equivalent amounts of CaO , for the remaining 0.09 per cent of water (hydroxyl) an equivalent of chlorine, and calculating to 100 per cent. For comparison, the theoretical composition corresponding to the formula $\text{Pb}_6\text{Ca}_4\text{Cl}_2(\text{Si}_2\text{O}_7)_3$ is also given.

	Analysis corrected.	Theory.
SiO_2	18.32	18.21
PbO	67.32	67.68
CaO	11.59	11.33
Cl	3.57	3.59
	<u>100.80</u>	<u>100.81</u>
$\text{O} = 2\text{Cl}$	0.80	0.81
	<u>100.00</u>	<u>100.00</u>

Before the blowpipe, nasonite is very apt to decrepitate, but if a fragment can be held in the forceps it fuses at about 2 to a semi-transparent globule, and the characteristic flame coloration of lead is obtained. In the closed tube the mineral gives a trace of water and an abundant sublimate of lead chloride, the residual mineral fusing to an amethystine glass in the bottom of the tube. The powdered mineral, when heated alone on charcoal in the reducing flame, gives a white sublimate of lead chloride distant from the assay, a yellow coating of oxide nearer, and globules of metallic lead. The mineral is readily soluble

in dilute nitric acid, and the solution yields gelatinous silica upon evaporation.

The mineral is named after Mr. Frank L. Nason of West Haven, Connecticut, formerly of the Geological Survey of the State of New Jersey.

Note concerning the Chemical Composition of GANOMALITE.

Nasonite is closely related to ganomalite, to which the empirical formula $Pb_8Ca_2Si_8O_{11}$ has been assigned, a little calcium being replaced by manganese. The foregoing formula, when doubled, may be written as a slightly basic salt, as follows: $Pb_4(Pb_2O)''Ca_4(Si_2O_7)_3$, which is like the formula of nasonite, except that the bivalent basic lead oxide radical (Pb_2O) of ganomalite takes the place of the two univalent lead chloride radicals ($PbCl$) of nasonite. The analogy between the two minerals, however, becomes still closer if two univalent lead hydroxide radicals ($PbOH$) are substituted for the bivalent basic lead oxide radical as follows: $Pb_4(PbOH)_2Ca_4(Si_2O_7)_3$, and we hope to be able to show that this is undoubtedly the correct formula for ganomalite. The amount of water necessary to yield two hydroxyls in the complex ganomalite molecule is a trifle less than one per cent, a quantity which might have been easily overlooked. In two analyses of ganomalite from Jakobsberg, Sweden, by Wiborgh, quoted by Sjögren,* neither water nor loss on ignition are recorded, while in an analysis by Lindström† a loss on ignition of 0.57 per cent is given, and, what is also very significant, the presence of a little chlorine is recorded. Lindström's analysis is as follows:

Analysis.			Ratio.		Analysis recalculated.	Theory for $Pb_4(PbOH)_2Ca_4(Si_2O_7)_3$.	
SiO ₂	18.33		0.306	3.00	SiO ₂	18.51	18.56
PbO	68.80		0.308	3.02	PbO	69.46	68.97
MnO	2.29	0.032	0.202	1.98	CaO	11.40	11.55
MgO	0.11	0.003			H ₂ O	0.63	0.92
CaO	9.34	0.167				100.00	100.00
Cl	0.24	0.007	0.070	0.70			
Ign.	0.57 ÷ 9 = 0.063						
†X	0.35						
	100.03						

* Geol. För. Förhandl., vi, p. 537, 1883.

† Ibid., p. 663.

† X = CuO 0.02, Al₂O₃ 0.07, Fe₂O₃ 0.12, alkali 0.10, P₂O₅ 0.04.

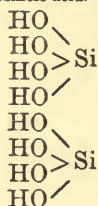
The ratio of $\text{SiO}_2 : \text{PbO} : \text{CaO} : (\text{OH} + \text{Cl}) = 3.00 : 3.02 : 1.98 : 0.70$, or, excepting the hydroxyl and chlorine, a very close approximation to $3 : 3 : 2 : 1$, thus agreeing with the ratio of nasonite. The water (loss on ignition) is low, owing undoubtedly either wholly or in part to the partial oxidation of the manganese during ignition. It is also possible that a trace of fluorine was present, since the amount necessary to bring the ratio of $(\text{OH} + \text{Cl} + \text{F})$ up to 1 would be trifling and might easily be overlooked. In connection with Lindström's analysis we have given his values recalculated to 100 per cent, after substituting an equivalent of CaO for the small amounts of MnO and MgO , an equivalent of water (hydroxyl) for chlorine, and disregarding the 0.35 per cent designated as X. The theoretical composition corresponding to the formula $\text{Pb}_4(\text{PbOH})_2\text{Ca}_4(\text{Si}_2\text{O}_7)_8$ is also given, and, except for the water, which is 0.31 per cent low, the agreement between the recalculated analysis and the theory is most satisfactory.

Ganomalite is tetragonal, and, in all probability, nasonite crystallizes in the same system, for, as already stated, the latter is optically uniaxial and breaks out into rude rectangular blocks, corresponding to the form produced by a combination of the prismatic and basal cleavages. The cleavage of nasonite, however, should be designated as poor, scarcely distinct, while ganomalite is described as having distinct cleavages parallel to the prism $m(110)$ and the base. Both minerals exhibit strong positive birefringence. The specific gravity of nasonite, 5.425, is less than that of ganomalite, 5.738, which would be expected, for, although nasonite contains chlorine which is heavier than hydroxyl, ganomalite contains more lead and hence should be heavier. The percentages of lead, according to theory are, respectively, nasonite 67.28 and ganomalite 68.98. Thus in their physical properties nasonite and ganomalite are closely analogous, and it may be confidently expected, on the one hand, that if crystals of nasonite are discovered they will be tetragonal, thus conforming to ganomalite, while, on the other hand, ganomalite will be found to contain water in sufficient quantity to yield

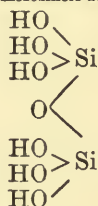
with the chlorine a ratio of $\text{SiO}_2 : (\text{OH} + \text{Cl}) = 3 : 1$. The two minerals furnish an excellent example of the isomorphous relation existing between chlorine and hydroxyl in complex molecules, nasonite being essentially the pure chlorine compound but containing a trace of hydroxyl (water), and ganomalite being essentially the pure hydroxyl compound but containing a trace of chlorine. Both minerals contain a little manganese isomorphous with the calcium.

Mesosilicic Acid. — The acid, $\text{H}_6\text{Si}_2\text{O}_7$, of which nasonite and ganomalite are salts, is intermediate between orthosilicic acid, H_4SiO_4 , and metasilicic acid, H_2SiO_3 , and it may be regarded either as equivalent to their algebraic sum, or as derived from two molecules of orthosilicic acid by taking away one molecule of water. The latter relation may be expressed as follows:

Two molecules of
orthosilicic acid.



Intermediate or
mesosilicic acid.



The intermediate acid $\text{H}_6\text{Si}_2\text{O}_7$ is one which has been recognized by mineralogists, but its salts have not generally received a prominent place in the systematic classifications of silicates, because they are not very numerous. Groth* calls attention to the acid and its salts, and has given the name "*Diorthokieselsäure*" to the acid. Clarke† also has discussed the chemical relations of the minerals of this group, adopting Groth's name *diorthosilicic acid*, and calling the minerals *diorthosilicates*. The name *diorthosilicic* seems, however, inappropriate, since $\text{H}_6\text{Si}_2\text{O}_7$ is not an orthosilicic acid as the name signifies, but a derivative of orthosilicic acid. We feel, therefore, war-

* Tabellarische Uebersicht der Mineralien, IV. Auflage, p. 105 and 140.

† Constitution of the silicates; Bull. of U. S. Geolog. Survey, No. 125, p. 81.

ranted in suggesting new names, *mesosilicic* for the acid and *mesosilicates* for its salts, the prefix *meso* being derived from μέσος, signifying middle or between. The intermediate relation of mesosilicic acid is evident from the following:

Orthosilicic acid, two molecules, $\text{H}_8\text{Si}_2\text{O}_8$.

Mesosilicic acid, $\text{H}_6\text{Si}_2\text{O}_7$.

Metasilicic acid, two molecules, $\text{H}_4\text{Si}_2\text{O}_6$.

The mesosilicates are classed by Dana in the small group of "Intermediate Silicates" on page 416 of his *Mineralogy*, and by Groth as "*Intermediäre Silikate*" on page 138 of his *Uebersicht der Mineralien*.

The commonest mesosilicate is iolite, the composition of which may be expressed as a slightly basic salt, as follows: $(\text{Mg}, \text{Fe})_4\text{Al}_6(\text{AlOH})_2(\text{Si}_2\text{O}_7)_6$, although the two hydroxyls may be in combination with the bivalent metals instead of with the aluminium. One of the few lead silicates, barysilite, $\text{Pb}_3\text{Si}_2\text{O}_7$, is a normal salt of mesosilicic acid, as is also the Franklin mineral hardystonite, $\text{Ca}_2\text{ZnSi}_2\text{O}_7$, recently described by Wolff.* Hardystonite is said to occur at the Parker shaft, North Mine Hill, but we have not yet observed it associated with any of the new minerals described in the present paper.

4. LEUCOPHÆNICITE.

This mineral made up the larger part of a specimen about two inches in length and breadth by one inch in thickness, which was found by Mr. J. J. McGovern of Franklin, and given to C. H. Warren in 1897. It has also been observed in small amount on a few specimens sent to us by Mr. W. M. Foote. The mineral has a crystalline structure, vitreous luster, hardness about 5.5–6, and is conspicuous on account of its light purplish-red or raspberry color. It was supposed at first to be clinohedrite, rather deeply colored by manganese. It is intimately associated with willemite of almost gem-like quality and beautiful light green color, and with small idiomorphic crystals of brown vesuvianite, showing prisms of the first and

* Proceedings of the Am. Acad. of Arts and Sci., xxxiv, 479, 1899.

second order, pyramid of the first order and base. Occasional crystal faces were observed on the leucophœnicite, but none which gave any clue to the system of crystallization.

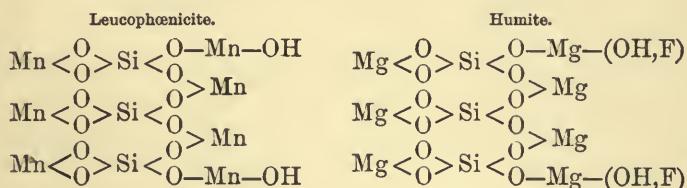
When small fragments of the mineral are imbedded in balsam and examined with the microscope it may be seen that the fragments are mostly irregular, although some are flat and appear to lie upon imperfect cleavage faces. There also may be seen irregular cracks indicating a second but not distinct cleavage. In polarized light the extinction seemed to be slightly inclined to the direction of the second cleavage, and in convergent light an optical axis was observed near the limit of the field. The fragments showed a slight pleochroism, pale rose for vibrations parallel to the direction of cleavage, and colorless at right angles to this direction. These properties indicate that the material probably crystallizes in one of the inclined systems, although wholly satisfactory conclusions could not be drawn.

Very pure material for the chemical analysis was obtained by crushing a portion of the best specimen, and selecting the purest particles by hand. The specific gravity was found to be 3.848. The results of the analysis by Warren are as follows:

	I.	II.	Average.	Ratio.	
SiO ₂	26.31	26.41	26.36	0.439	3.03
MnO	60.59	60.67	60.63	0.854	} 1.015 7.00
ZnO	4.03	3.72	3.87	0.047	
FeO			trace		
MgO	0.21		0.21	0.005	
CaO	5.64	5.70	5.67	0.101	
Na ₂ O	0.39		0.39	0.006	} 1.01
K ₂ O	0.24		0.24	0.002	
H ₂ O	2.70	2.58	2.64	0.146	
100.01					

Letting R stand for the metals (chiefly manganese), the ratio of SiO₂ : RO : H₂O is 3.03 : 7.00 : 1.01, or a close approximation to 3 : 7 : 1, and this leads to the general empirical formula H₂R₇Si₃O₁₄. Since water is not expelled from the mineral

much below a red heat, the hydrogen must exist in the form of hydroxyl, and, consequently, the foregoing formula may be written $R_5(\text{ROH})'_2(\text{SiO}_4)_3$ or as a basic orthosilicate, exactly equivalent to humite except that no fluorine is present. Considering the base wholly as manganese, the following is suggested as a structural formula of the mineral, which certainly appears simple and reasonable. For comparison the structural formula of humite is also given.



Leucophœnicite is therefore a manganese humite, but it contains no fluorine isomorphous with the hydroxyl. As humite is a magnesium mineral resulting from metamorphism due to fumarole or pneumatolitic action, so leucophœnicite is a similarly constituted mineral, produced probably by like causes at a locality where manganese was abundant. It is probable that the crystallization of leucophœnicite is analogous to that of the minerals of the humite group, and, since the examination of fragments of leucophœnicite in polarized light indicated one of the inclined systems (page 340), it may be inferred that its crystallization is monoclinic, with $\beta = 90$, analogous to chondrodite and clinohumite, rather than orthorhombic like humite. Furthermore, the discovery of this mineral suggests the possibility of finding a series of manganese compounds, corresponding to prolectite, chondrodite, humite, and clinohumite. Attention may also be called to the fact that Jannasch and Locke* have described a variety of humite from Valais, Switzerland, exactly analogous to leucophœnicite in that it contains no fluorine.

Before the blowpipe, leucophœnicite fuses quietly at about 3 to a brownish black globule. In the closed tube it yields a

* Zeitschr. für anorganische Chemie, vii, p. 92, 1894.

little water. Reacts for manganese with the fluxes. The powdered mineral dissolves very easily in hydrochloric acid, and the solution yields gelatinous silica upon evaporation.

The name leucophœnicite has reference to the color of the mineral, and was derived from λευκός = pale or light, and φοίνιξ = purple-red.

There are other minerals from the locality, some of them evidently new, which have been partially examined, and it is hoped that a full description of them may be given in a future article.

In closing we desire to express our thanks to those gentlemen, named at the beginning of this article, who have generously supplied us with material for carrying on this investigation, and especially to Mr. W. M. Foote, who spent some weeks collecting at the locality in the summer of 1898 and who has called our attention to a number of interesting specimens and associations.

ON THE CHEMICAL COMPOSITION OF SULPHOHALITE.

By S. L. PENFIELD.

(From Amer. Jour. Sci., 1900, vol. 9, pp. 425-428.)

THE rare species sulphohalite was first described in 1888 by W. E. Hidden and J. B. Mackintosh * as a mineral of unusual composition, a double sulphate and chloride of sodium corresponding to the formula $3\text{Na}_2\text{SO}_4 \cdot 2\text{NaCl}$. It was found associated with the then recently discovered hanksite, at the famous Borax Lake locality, San Bernardino County, California. It crystallizes in rhombic dodecahedrons, belonging to the isometric system and measuring at times over 30 mm. in diameter. According to information received from Mr. Hidden, only a few specimens of the mineral were found. Two of these are in the collection of Mr. C. S. Bement of Philadelphia, and one in the British Museum, while the type

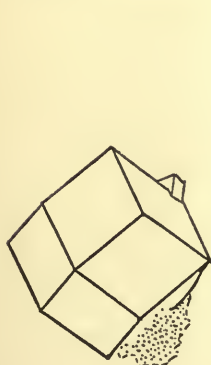


FIGURE 1.

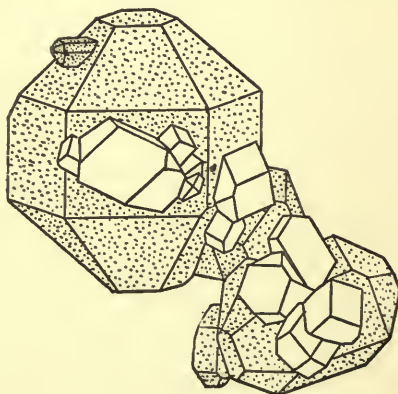


FIGURE 2.

* Amer. Jour. Sci., 1888, vol. 36, p. 463.

specimen from which material for the original analysis by Mackintosh was obtained, was retained by Mr. Hidden. This latter specimen has been generously presented to the writer, with the understanding that part of it should be used for a new analysis and the remainder deposited in the Brush Collection of the Sheffield Scientific School.

Figures 1 and 2 represent the two specimens in the Bement Collection, natural size. The one represented by Figure 1 is a rhombic dodecahedron of almost ideal development, slightly yellowish in its tone of color, and nearly transparent. A very little gangue, chiefly hanksite, and a few small crystals of sulphohalite are the only things attached to this superb crystal, and the specimen can be so held that only small portions of these are visible. The second specimen, Figure 2 consists of a group of three large and a few small hanksite crystals upon which a number of sulphohalite dodecahedrons have grown. The figure is merely a sketch, hence it is not to be considered as an exact crystal drawing; however, pains have been taken to represent the crystals in their proper size and proportions, and, for the sake of distinctness, the hanksite crystals have been stippled. All of the sulphohalite crystals are distributed on one side of this specimen only.

The writer's attention was directed to the desirability of reinvestigating this species by the following circumstances: In January of the previous year, a letter was received from Prof. A. de Schulten of the University of Helsingfors, Finland, stating that he had repeatedly attempted to reproduce sulphohalite artificially, but always obtained sodium chloride and sodium sulphate, crystallizing respectively as halite and thenardite. As he was unable to obtain specimens of sulphohalite from mineral dealers, he appealed to the writer to make if possible a new analysis of the mineral, and, if this should conform to the composition as given by Mackintosh, he expressed his determination to proceed with his endeavors to make the mineral by artificial means. A short time previous, in an article entitled "*Die Bildungsverhältnisse der oceanischen Salzablagerungen*" by J. H. van't Hoff and A. P.

Saunders,* the probable non-existence of sulphohalite had been set forth. This decision was based chiefly upon the failure of these investigators to obtain by artificial means a double sulphate and chloride of sodium corresponding to the composition as given by Mackintosh, their experiments, like those of de Schulten, yielding crystals of halite and thenardite. They furthermore endeavored to secure sulphohalite specimens from dealers, and two small and very expensive ones that were sent to them proved upon examination to be simply fragments of halite. Lastly, a request came from Mr. Hidden that the present writer should make a new analysis of sulphohalite, for the purpose of definitely establishing the identity of the species and its chemical composition, and the request was accompanied by the gift of the precious material.

The material submitted for examination was part of a rhombic dodecahedron which must have originally measured about 30 mm. in diameter. To it were attached several small prismatic crystals of hanksite. The sulphohalite material was clear, transparent, and homogeneous, and when tested with the polarizing microscope it was found to be isotropic. The fracture is small conchoidal, and the absence of any distinct cleavage is noticeable, thus distinguishing it from halite. The material for analysis, after being carefully selected was crushed and sifted to a nearly uniform grain, and separated by means of methylen iodide diluted with benzol. Nearly all of the material ranged in specific gravity within the narrow limits 2.493 and 2.506. The average of these determinations, 2.500, may be taken as the correct specific gravity, which is close to that given by Hidden and Mackintosh, 2.489. The material thus separated, when tested with acid, gave no effervescence, thus indicating perfect separation from hanksite. A few fragments, mostly hanksite, which were heavier than the product separated for analysis, effervesced with acids, hence failure to make a complete separation from hanksite undoubtedly accounted for the small percentage of Na_2CO_3 recorded in Mackintosh's analysis.

* Sitzungsberichte der k. Akad., Berlin, 1898, vol. 1, p. 387.

After completing the quantitative determinations of Cl , SO_3 , and Na_2O , the constituents required by the formula as given by Mackintosh, a deficiency was noted in the analysis, which for a time proved very perplexing, but led finally to the discovery of another and rather unexpected constituent, namely fluorine. In recording the analysis, sufficient sodium has been taken to combine with the chlorine and fluorine to form the molecules NaCl and NaF , respectively, while the remainder of the sodium is given as oxide.

The results of the analysis are as follows :

		Ratio.		Calculated for $2\text{Na}_2\text{SO}_4 \cdot \text{NaCl} \cdot \text{NaF}$.	Results of Mackintosh.
SO_3	41.79	0.522	2.00	41.61	42.48
Na_2O	32.37	0.522	2.00	32.25	...
K_2O	0.10	...	...	...	...
Na	11.60	...	...	11.97	...
Cl	9.10	0.256	0.98	9.23	13.12
F	4.71	0.248	0.95	4.94	...
Ign.	0.15	...	...	...	Na_2CO_3 1.77
				<u>99.82</u>	<u>100.00</u>

The ratio of $\text{SO}_3 : \text{Na}_2\text{O} : \text{Cl} : \text{F}$ approximates closely to 2 : 2 : 1 : 1, and since the sodium (Na) recorded is just sufficient to unite with the chlorine and fluorine, the formula of sulphohalite becomes $2\text{Na}_2\text{SO}_4 \cdot \text{NaCl} \cdot \text{NaF}$. Fluorine was weighed as calcium fluoride, and the purity of the product was proved by converting it into calcium sulphate. It is interesting to note the association of this mineral, having three acid constituents, with hanksite, which also has three acid constituents, its composition, according to the investigation of Pratt,* being $9\text{Na}_2\text{SO}_4 \cdot 2\text{Na}_2\text{CO}_3 \cdot \text{KCl}$. Although the presence of fluorine in sulphohalite was wholly unexpected and seemed at first surprising, the occurrence of that constituent in some mineral from the Borax Lake locality is not to be wondered at. This important deposit of borax has been formed undoubtedly from fumarole or solfataric action, and it is well established that

* Page 273.

volcanic gases frequently give rise to fluorine as well as to boron, chlorine, and sulphuric acid compounds.

Probably the name sulphohalite would not have been given to this mineral had its composition been correctly determined by Mackintosh; however, one would scarcely be justified at the present time in assigning a new name to the compound. To a certain extent van't Hoff and Saunders were correct in calling attention to the probable non-existence of the species, for, although the mineral in name and substance had an existence, a double salt of the composition $3\text{Na}_2\text{SO}_4 \cdot 2\text{NaCl}$ as originally ascribed to sulphohalite is not known, and, apparently, cannot be made by artificial means.

It is needless to speculate as to how Mackintosh, who was an experienced and careful worker, made an erroneous analysis. His determination of SO_3 was nearly correct, while that of chlorine was four per cent too high. In one respect he certainly made a decided mistake, namely in not completing his analysis by determining the amount of sodium, for, had he done so, he probably would have noted a deficiency and this naturally would have led to the discovery of the missing constituent.

Mineralogists certainly are indebted to Mr. Hidden for the discovery of this exceptionally beautiful and interesting mineral, while his eagerness to have the species correctly investigated, together with his generosity in supplying the necessary material have enabled the writer to carry on this investigation. Thanks also are due to Mr. Bement for the loan of his valuable specimens.

ON THE INTERPRETATION OF MINERAL ANALYSES: A CRITICISM OF RECENT ARTICLES ON THE CONSTITUTION OF TOURMALINE.

By S. L. PENFIELD.*

(From Amer. Jour. of Sci., 1900, vol. 10, pp. 19-32.)

ABOUT eighteen months have elapsed since H. W. Foote and the present writer published a joint article on the chemical composition of tourmaline.† Since that time two articles have appeared, presenting views differing from one another and from those of Foote and the author; one on the Constitution of Tourmaline, by Prof. F. W. Clarke ‡ of Washington, the other *Ueber das Mischungsgesetz der Turmaline*, by Prof. G. Tschermak § of Vienna.

In order to discuss the views presented in these articles, it is desirable to carefully consider some facts concerning chemical analyses. In the first place, a perfect chemical analysis cannot be made. There are, to be sure, a very few analytical processes for the determination of single constituents, which, when carefully executed, can be relied upon to give results varying less than 0.01 per cent from the theory; but when it comes to mineral analysis, necessitating the splitting up of a complex body and the determination of a number of constituents, such accuracy cannot be attained. In making a mineral analysis, one seldom feels confident that all determinations are correct, even within 0.25 per cent of the truth, although if duplicate analyses are made, it is expected that, for the majority of the constituents at least, the two determinations will agree within 0.10 or 0.20 per cent of one

* Only a portion of this paper, treating of the Interpretation of Mineral Analyses, is here presented. — Error.

† Page 297.

‡ Amer. Jour. Sci., 1899, vol. 8, p. 111.

§ Mineralog. und Petrogr. Mitth., 1899, vol. 19, p. 155.

another. At times, of course, depending upon the difficulty of the analysis or the scarcity of available material, variations of 0.50 per cent, or even more, in duplicate determinations are not to be wondered at.

Secondly, analytical work may be of a high order, the results very accurate, and yet an analysis may not serve for the determination of a chemical formula because made on material more or less impure. The chemists of to-day have a decided advantage over those of a former generation, for the microscope enables them to study their material, select that which is best, and, if impurities cannot be avoided, to take their effect into consideration in discussing the analytical results. Then again the heavy solutions are invaluable for separating out material for analysis, and, what is considered of very great importance, for furnishing a guarantee of the purity of any given material; for if it can be stated that all of the mineral floats on a solution of a certain specific gravity and sinks when the specific gravity is lowered to a trifling extent, it gives one not only great confidence in the purity of the material, but, also, it enables the investigator to present data which others may make use of in judging the character of the work.

It has been the author's privilege during the past twenty-five years to make many analyses of minerals, and to superintend the making of many more in the Sheffield Mineralogical Laboratory; also to discuss the analytical results and derive therefrom the chemical formulas of minerals, and this occasion will be taken to call attention to certain features which are regarded as most important in mineralogical investigations. In the first place, the utmost pains should be taken to secure pure material, and, if the results are to be published, the character of the material should be described, so that its degree of purity can be judged by others. Secondly, if an analysis presents any especially difficult features, the method of analysis should be carefully described, and it is in almost all cases well to give at least some brief outline of the analytical methods employed. Then, too, when material is abundant, it is advisable to make analyses in duplicate, and to give all of the

determinations, together with the averages. Thus the investigator has from beginning to end the satisfaction of a control over all determinations, and, if agreements are close, others can form some estimate concerning the care with which the work was executed. There are those who apparently entertain the belief that closely agreeing duplicate determinations indicate great accuracy in analytical work, but that is not necessarily the case, for in some analytical methods there is a tendency for results to come too high, in others too low, and thus duplicate determinations, made under like conditions, either with faulty methods, or with good methods improperly executed, may be uniformly high or uniformly low, agreeing with one another, and yet varying considerably from the truth. Still two closely agreeing determinations carry with them a certain weight which cannot be ignored. Thirdly, with each analysis, the quotients obtained by dividing the several constituents by their molecular or atomic weights, as the case demands, should be given, and from the quotients thus obtained the ratio between the several constituents should be determined. The ratio ought not to be given simply rounded out to the nearest whole numbers, but, taking the quotient of the most characteristic or best determined constituent as unity, the ratio should be given to the second place of decimals. *It is safe to assume that the close approximation of a ratio to whole numbers constitutes the strongest argument that can be advanced in support of the excellence of an analysis and the correctness of the derived formula.* It will seldom happen that a ratio approximates to whole numbers merely as a matter of accident. Provided the compound is a simple one, instead of giving the ratio, an excellent method is to give the calculated composition, which can then be compared directly with the results of the analysis. Lastly, for determining a formula one or two good analyses are of more value than many indifferent ones, hence it will often prove best to make new analyses on material of unquestioned purity. This may be done not wholly with the idea that the new analyses are better than those made by other investigators, but, knowing

all about the quality of the material and the working of the analyses, it will be possible to exercise better judgment in summing up the results of the investigation, and to present with greater force the arguments needed in support of the proposed formula.

Turning now to the consideration of tourmaline, two new analyses were made by Foote and the author, upon material of ideal purity and with the use of most carefully studied methods. The results, given on page 310, need not be repeated here, but it will be stated that, with the exception of a single water determination, all constituents were determined in duplicate; that in twenty out of a total of twenty-three instances, the discrepancy between duplicate determinations did not exceed 0.10 per cent; and that the maximum variation in the remaining three instances was 0.18 per cent. The single water determination which was not duplicated was controlled by a closely agreeing estimation of loss on ignition. In working out the ratios from these analyses, the method was adopted of calculating for the metals their equivalent of hydrogen, including fluorine with hydrogen, since tourmaline contains hydroxyl with which fluorine is isomorphous. Thus the ratio was found between $\text{SiO}_2, \text{B}_2\text{O}_3$, and Total Hydrogen, from which the empirical formula of the tourmaline acid was derived. For the sake of the present discussion the ratios will be repeated in two forms: with one-fourth of the SiO_2 as unity and also with one-twentieth of the Total Hydrogen as unity. This latter method has been here adopted, because a few relations can be brought out better in the discussion by so doing. The ratios of the two analyses are then as follows:

	SiO_2	:	B_2O_3	:	Total H.	SiO_2	:	B_2O_3	:	Total H.
De Kalb	4.00	:	1.01	:	19.90	4.02	:	1.01	:	20.00
Haddam Neck	4.00	:	1.02	:	19.98	4.00	:	1.02	:	20.00

These ratios approximate *very closely* to the whole numbers 4 : 1 : 20; such close approximations, in fact, are seldom obtained, and cannot in these two instances be regarded merely as matters of accident; they are the reward, rather, of careful

analytical work on material of unquestionable purity. As soon as the ratios were worked out, it was seen at once that at least one important key to the solution of the tourmaline problem had at last been found: *the empirical formula of the tourmaline acid must be $H_{20}B_2Si_4O_{21}$.*

And now, for the sake of the discussion, some space will be devoted to the ratios derived from the analyses of Riggs, and Jannasch and Kalb. These have already been given by Foote and the author * with $\frac{1}{4}SiO_2$ as unity, and are now repeated, together with the ratios derived by taking $\frac{1}{2}H$ Total Hydrogen as unity. They have moreover been arranged in series, commencing with the closest approximation to 4 : 20 between SiO_2 and Total Hydrogen, and proceeding to the maximum deviation from this ratio.

TOURMALINE RATIOS DERIVED FROM THE ANALYSES OF RIGGS.

No.	No. in Dana's Mineralogy.	SiO_2	:	B_2O_3	:	Total H.	SiO_2	:	B_2O_3	:	Total H.
1.	43.	4.00	:	0.94	:	20.03	3.99	:	0.94	:	20.00
2.	45.	4.00	:	0.95	:	20.03	3.99	:	0.95	:	20.00
3.	48.	4.00	:	1.01	:	20.06	3.99	:	1.00	:	20.00
4.	47.	4.00	:	0.98	:	20.08	3.98	:	0.97	:	20.00
5.	52.	4.00	:	0.94	:	20.11	3.98	:	0.93	:	20.00
6.	49.	4.00	:	1.01	:	20.12	3.97	:	1.00	:	20.00
7.	36.	4.00	:	0.90	:	20.2	3.96	:	0.89	:	20.00
8.	44.	4.00	:	0.88	:	20.2	3.96	:	0.87	:	20.00
9.	46.	4.00	:	0.96	:	20.2	3.96	:	0.95	:	20.00
10.	42.	4.00	:	0.97	:	19.8	4.04	:	0.98	:	20.00
11.	54.	4.00	:	0.98	:	19.8	4.04	:	0.99	:	20.00
12.	39.	4.00	:	0.94	:	19.7	4.06	:	0.95	:	20.00
13.	41.	4.00	:	0.92	:	19.7	4.06	:	0.93	:	20.00
14.	51.	4.00	:	0.91	:	19.6	4.08	:	0.93	:	20.00
15.	37.	4.00	:	0.93	:	20.5	3.90	:	0.91	:	20.00
16.	38.	4.00	:	0.92	:	19.5	4.10	:	0.93	:	20.00
17.	55.	4.00	:	1.01	:	20.6	3.88	:	0.98	:	20.00
18.	40.	4.00	:	0.96	:	19.3	4.14	:	1.00	:	20.00
19.	50.	4.00	:	0.98	:	19.2	4.16	:	1.02	:	20.00
20.	53.	4.00	:	0.97	:	18.9	4.23	:	1.00	:	20.00
Average		4.00	:	0.95	:	19.88	4.02	:	0.96	:	20.00

* Pages 312 and 313.

TOURMALINE RATIOS DERIVED FROM THE ANALYSES OF
JANNASCH AND KALB.

No.	No. in Dana's Mineralogy.	SiO ₂	:	B ₂ O ₃	:	Total H.	SiO ₂	:	B ₂ O ₃	:	Total H.
1.	62.	4.00	:	0.80	:	20.00	4.00	:	0.80	:	20.00
2.	64.	4.00	:	0.84	:	20.01	4.00	:	0.84	:	20.00
3.	61.	4.00	:	0.95	:	20.2	3.96	:	0.94	:	20.00
4.	57.	4.00	:	0.99	:	19.8	4.04	:	1.00	:	20.00
5.	56.	4.00	:	0.96	:	19.7	4.06	:	0.97	:	20.00
6.	63.	4.00	:	0.98	:	19.7	4.06	:	0.99	:	20.00
7.	58.	4.00	:	0.95	:	20.4	3.92	:	0.93	:	20.00
8.	60.	4.00	:	0.88	:	20.4	3.92	:	0.86	:	20.00
9.	59.	4.00	:	0.92	:	18.8	4.25	:	0.98	:	20.00
Average		4.00	:	0.92	:	19.9	4.02	:	0.93	:	20.00

Before entering upon the discussion of these ratios, let it be understood that the analysis of tourmaline is one of the difficult problems of analytical chemistry, and although Riggs made duplicate and often triplicate determinations of B₂O₃ and H₂O in almost all cases, and duplicated somewhat more than half of his determinations of SiO₂ and F, only single determinations of other constituents are recorded in his paper, while Jannasch and Kalb record only single determinations. Also it is to be borne in mind that although both Riggs and Jannasch and Kalb undoubtedly used carefully selected tourmaline fragments for analysis, still there is nothing to indicate that slight amounts of foreign materials might not have been present in some of the specimens analyzed. Keeping these facts then well in mind, let us examine the ratios as presented in the foregoing tables. It is granted that the ratios are not exactly 4:1:20, and to get *exact ratios* from mineral analyses is not to be expected, but the close approximation to 4:1:20 in the case of the two analyses by Foote and the author, of sixteen out of the twenty analyses by Riggs, and of eight out of the nine analyses by Jannasch and Kalb, *constitutes an overwhelming amount of evidence in support of the empirical formula of the tourmaline acid, H₂₀B₂Si₄O₂₁*. It is safe to state that there does not exist a series of thirty silicate analyses of any one mineral yielding ratios which approximate so closely to whole numbers

as the tourmaline analyses referred to above. That some analyses fail to yield a ratio as close to rational numbers as desired, reflects discredit neither upon the analyst nor upon the character of his work, for the material for analysis might not in all cases have been pure. Take, for example, No. 17 of the series of Riggs, brown tourmaline from Hamburg, N. J., occurring in calcite. The ratio of SiO_2 : Total Hydrogen = 4 : 20.6. Evidently the bases are too high, and this particular analysis is peculiar in that it shows 5.09 per cent CaO, while the next highest percentage of CaO recorded in any of the published analyses is 3.70. The material from Hamburg might well have contained some calcite, either as small included nodules, or as an infiltration along cracks, and if the amount of calcite be assumed as 1.78 per cent, equivalent to 1 per cent CaO, the analysis would add up to 100.82, which is not too high for such a complicated substance, and the ratio of SiO_2 : Total Hydrogen would become 4.00 : 20.3 or 3.94 : 20.00. To assume that the Hamburg material probably contained some calcite seems far more reasonable than to speculate, upon some complex formula especially adapted to suit this particular analysis. Again, Nos. 18, 19, and 20 of Riggs, and 9 of Jannasch and Kalb indicate either that the amount of base is low, SiO_2 being assumed as practically correct, or, what is far more likely, that the amount of SiO_2 is too high, as seen best when one-twentieth of the Total Hydrogen is taken as unity. Does the high silica ratio indicate that for these special cases a new type of tourmaline formula is needed, or is it not simpler to assume that the material from which these analyses were made might possibly have contained a little quartz or other silicate as impurity? It would take not over 2 per cent of quartz as an impurity to bring about the extreme amount of variation from the ratio 4 : 20 recorded in the foregoing tables.

Summary. — As shown by the tabulation of ratios on pages 351 to 353 there exist a series of recently made and carefully executed tourmaline analyses which give ratios of SiO_2 : B_2O_3 : Total Hydrogen approximating closely to 4 : 1 : 20, from which the empirical formula of the tourmaline acid, $\text{H}_{20}\text{B}_2\text{Si}_4\text{O}_{21}$, is

derived. That a few analyses do not yield ratios agreeing as closely as desired to 4:1:20 is not to be wondered at, when the difficulties presented by the analysis are taken into consideration, together with the fact that the material analyzed might not in all cases have been perfectly pure and homogeneous. As far then as analytical evidence may be relied upon for establishing the formula of a mineral, it may be considered *as definitely proved that the empirical formula of the tourmaline acid is* $H_{20}B_2Si_4O_{21}$. The science of inorganic chemistry has not yet reached such a state of development that it can be proved, as claimed by Tschermak, that the threefold formula, $H_{60}B_6Si_{12}O_{63}$, is the correct one. The empirical formula $H_{30}B_3Si_6O_{31}$, proposed by Clarke, can rest only on the analytical evidence supplied by a few analyses of Riggs and one by Jannasch and Kalb which yield ratios approximating to 4:1:19.33 (pages 352 and 353), and there are good reasons for believing that these ratios would not be obtained a second time if the analyses were repeated. Since tourmaline always yields sufficient water to form two hydroxyl radicals, it may be considered *as probably, if not absolutely, proved that the formula of the tourmaline acid should be* $H_{18}(OH)_2B_2Si_4O_{19}$. Beyond this point it seems safe only to speculate and it cannot be considered that the ideas presented are capable of being definitely proved. All of the analyses indicate that at least half of the hydrogen atoms of the tourmaline acid are replaced by aluminium, and this fact, coupled with the idea that it seems reasonable to unite the two hydroxyl radicals with the two boron atoms, led to the suggestion by Foote and the author (p. 317) that the characteristic feature of all varieties of tourmaline is an *aluminium-borosilicic acid* $H_9Al_3(BOH)_2Si_4O_{19}$. In this acid the mass effect of the $[Al_3(BOH)_2Si_4O_{19}]$ is regarded as so overwhelming that it makes no difference how the nine remaining acid hydrogen atoms are replaced, whether largely by aluminium and to a trifling extent by bivalent metals and alkalis, or largely by magnesium and to a trifling extent by aluminium and alkalis, the result in all cases is tourmaline with its characteristic crystalline structure. That

trivalent, bivalent, and univalent metals, playing as it were the rôle of isomorphous constituents, may unite in replacing the nine hydrogen atoms of the tourmaline acid, is indeed a remarkable feature of isomorphism, but it furnishes an explanation of the composition of tourmaline, and one which can be comprehended, at least to some extent.

ON SOME INTERESTING DEVELOPMENTS OF CALCITE CRYSTALS.

BY S. L. PENFIELD AND W. E. FORD *

(From Amer. Jour. Sci., 1900, vol. 10, pp. 237-244.)

1. CALCITE FROM UNION SPRINGS, CAYUGA COUNTY, N. Y.

THE crystals under consideration were found during the summer of 1899 by Mr. J. M. Clarke, of the Geological Survey of the State of New York, and were sent to New Haven for examination. Mr. Clarke had observed that the crystals presented certain features of unusual interest, and it was his wish that they should be described and that the specimens should be deposited in the Yale Collection. The crystals occur in the Onondaga limestone, in a region where slight tectonic disturbances have taken place, giving rise to fissures in which calcite has deposited as vein material. The most interesting feature presented by the crystals is their diversity of habit, shown often on a single hand specimen, and due to different methods of twinning together with peculiarities in the development of certain crystal faces.

Most of the crystals were not well adapted for measurement with the reflecting goniometer, but, using one of the smaller ones, about 5 mm. in length and 2 mm. in diameter, it was possible to identify the prominent forms by means of their angles. The small crystals are quite highly modified and their development is represented by Figure 1. The terminal faces

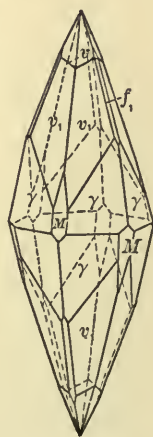


FIGURE 1.

* Reprinted in part.—EDITOR.

are the brightest and best developed, and are those of the common scalenohedron v (21 $\bar{3}$ 1). There was measured for the identification of this form r (cleavage) $\wedge v$, $10\bar{1}\bar{1} \wedge 21\bar{3}\bar{1} = 28^\circ 56'$, calculated $29^\circ 1' 30''$. In the zone r , v , and making a very small angle with v is the scalenohedron v_1 (7.4. $\bar{1}\bar{1}$.3) which is especially prominent on the crystals from this locality. This form was identified by von Bournon on crystals from Derbyshire and the Dauphine Alps, and appears as form No. 37, Plate 31, of his *Traité de Minéralogie*, published in 1808. The form was identified by its position in the zone r , v , and the measurement $v \wedge v_1 = 3^\circ 23'$, calculated $3^\circ 55'$. On the crystals under consideration the faces of the scalenohedron v_1 have a vicinal development, and thus the contrast between them and the better developed faces of the scalenohedron v is generally quite marked. A negative rhombohedron, f_1 , truncates the edges of v_1 and appears always as a narrow face with vicinal development from which no reflection could be obtained. A rhombohedron in this position would have the symbol (0.12. $\bar{1}\bar{2}$.5) and is a little steeper than the common rhombohedron f (02 $\bar{2}$ 1), which truncates the pole edges of the scalenohedron v . The pyramid of the second order γ (8.8. $\bar{1}\bar{6}$.3) was identified by the measurement $8.8.\bar{1}\bar{6}.3 \wedge 8.8.\bar{1}\bar{6}.\bar{3} = 25^\circ 40'$, calculated $24^\circ 46'$, and further, by its being truncated by the positive rhombohedron M , (40 $\bar{4}$ 1). This rare pyramid was first identified by vom Rath* on crystals from Andreasberg in the Harz, and, as pointed out by the present writers,† this same pyramid is the prevailing form of the siliceous calcites from the Bad Lands of South Dakota. On crystals from Union Springs there is a tendency for the upper and lower faces of the pyramid γ to round into one another, owing to vicinal development, and because of this rounding it was impossible to obtain an accurate measurement between the upper and lower γ faces.

On the majority of the specimens the crystals are not so highly modified as the one just described, but, as already stated,

* Pogg. Annalen, cxxxii, p. 521, 1867.

† Amer. Jour. Sci., 1900, vol. 9, p. 352.

the variation in habit due to twinning and the unequal development of certain faces, gives to the specimens a peculiar interest. All the types to be described occur on a single specimen having a surface about half the size of one's hand covered with crystals. The crystals on this specimen were not suitable for measurement and therefore no angles will be given, but the forms were evidently like those identified on the small crystal previously described.

Scalenohedral type.—The scalenohedron v_1 ($7.4.\bar{1}\bar{1}.3$) Figure 2, is apparently very common at the locality. It should be stated that this form has the same middle edges as the rhombohedron r ($10\bar{1}1$) and the common scalenohedron v ($21\bar{3}1$) but is somewhat steeper than the latter form. A twinning about the basal plane, Figure 3, is quite common.

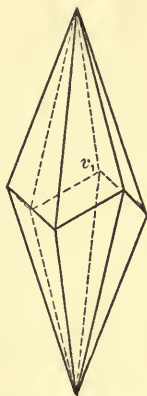


FIGURE 2.

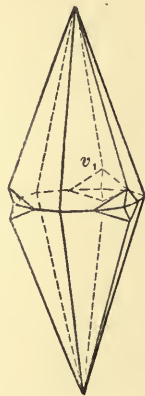


FIGURE 3.

Twins, with the rhombohedron e ($01\bar{1}2$) as twinning

plane. The habit resulting from this kind of twinning is like that of the well known Guanajuato calcites, described by Pirsson,* and it should also be stated that as early as 1837, Lévy† also described and figured calcite twins of this same type from Streifenberg, Nertschinsk, Siberia. Figure 4 (p. 360) is analogous to the figures of Pirsson and Lévy, though drawn in a different position, and represents the common scalenohedron v ($21\bar{3}1$) drawn with the twinning plane vertical and having a position like that of the side face of a cube, or the pinacoid 010 of any of the three axial systems. This position has been adopted for representing the twin crystals as it gives

* Amer. Jour. Sci., 1891, vol. 41, p. 61.

† Description d'une Collection de Minéraux formée par H. Heuland, vol. I, p. 10, Fig. 5, Plate 1.

the best idea of their peculiar development. Figure 5 represents the scalenohedron v_1 (7.4.11.3) twinned without distortion, a type which has not been observed on any of the specimens, but the figure is introduced in order to show how, by the extension of the two lettered faces in front and the parallel faces behind, together with the suppression of the four small faces below, the Guanajuato type, Figure 4, results.

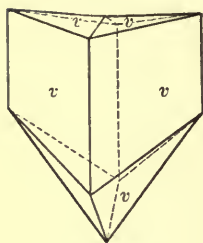


FIGURE 4.

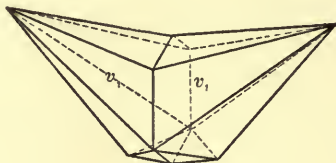


FIGURE 5.

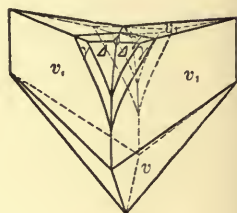


FIGURE 6.

Most of the Union Springs crystals of the Guanajuato type show in addition to the scalenohedron certain modifications at the reentrant angle, Figure 6. The faces forming the reentrant angle are the pyramid of the second order γ (8.8.16.3) and a rhombohedron designated as Δ , apparently in the zone with v_1 and γ , which would cause it to have the symbol (8083). The surfaces forming the gash or reentrant angle, however, are curved to such an extent that exact symbols cannot be assigned to portions of them.

Twins with the rhombohedron $f(02\bar{2}1)$ as twinning plane. — The rhombohedron f is one of the rare twinning planes of calcite, and the habit presented by the crystals from Union Springs is very striking. The scalenohedron v_1 (7.4.11.3) twinned about f , and drawn with the twinning plane vertical, as previously described, is represented by Figure 7. In the Union Springs crystals representing this twinning law the reentrant angle at the top wholly fails, and a peculiar, pointed, spear-head development, Figure 8, results from the extension of the two front lettered faces of Figure 7 and the corresponding faces at the back. The crystals observed have always

been attached at the lower end. Several crystals of this peculiar type were observed on the specimens sent by Mr.

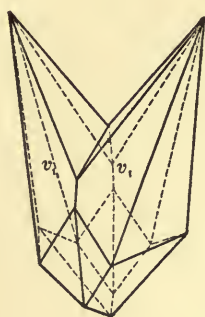


FIGURE 7.

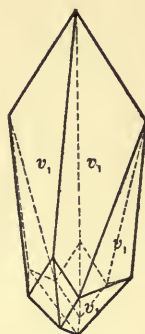


FIGURE 8.

Clarke, and they are said to be quite common at the locality. On a crystal with a broken point the reëntrant angle measured from the rhombohedral cleavages was found to be $35^{\circ} 38'$, calculated $35^{\circ} 27'$.

Lévy, in Figure 6 of the atlas to his work already cited, gives a representation of a crystal from Kongsberg in Norway, of identically the same habit as Figure 8 of this article; however, the habit is apparently a very unusual one, and it is interesting to record it at a new locality.

On a single specimen or even at one locality, as a rule all crystals of a certain mineral have the same or nearly the same habit, resulting undoubtedly from crystallization under uniform conditions, and therefore it seems a matter of more than usual interest to note on a single hand specimen from the Union Springs locality, the occurrence of simple scalenohedrons, Figure 2, and of three distinct types of twinning, Figures 3, 6, and 8. The calcite crystals seem to be all of one generation. Associated with them are a few crystals of dolomite, apparently of later growth.

2. BUTTERFLY TWINS FROM EGREMONT, CUMBERLAND, ENGLAND.

The so-called butterfly twins from Egremont are well-known and are figured in many mineralogies. Lévy in his work, already cited, gives three figures of them, No. 17, 68, and 69 of his atlas. A few words concerning them and new figures are introduced in the present article for the sake of comparison with the two types of rhombohedral twinning previously described. The twinning plane in these crystals is the rhombohedron r ($10\bar{1}1$), and the common scalenohedron v ($21\bar{3}1$) thus twinned, and drawn as in previous cases with the twin-

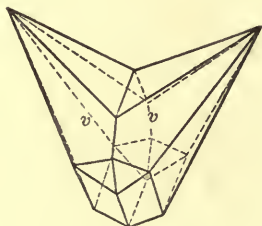


FIGURE 9.

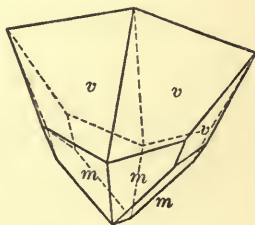


FIGURE 10.

ning plane vertical, is represented by Figure 9. Figure 10 represents a crystal of the butterfly twin type in the Brush Collection, and, by comparison with Figure 9, it may be seen that the upper faces of the crystal result from the development of the two front, lettered faces of Figure 9 and corresponding faces behind, to the complete obliteration of the reëntrant angle. The faces at the lower extremity of Figure 10 are those of the prism m , ($10\bar{1}0$).

It is a matter of interest to observe how the scalenohedron, when twinned as described according to the three rhombohedral laws, gives apparently simpler shapes by distortion, or unequal development of some of its faces, than if the distortion had not taken place.

3. CRYSTALS FROM PALLAFLAT, CUMBERLAND, ENGLAND.

A feature of the crystals from this locality, as represented by specimens in the Brush Collection, is the prominent development of the negative scalenohedron $x(1341)$. This form, as shown by Figure 11, has its shorter pole edges bevelled by the common scalenohedron $v(21\bar{3}1)$ and has the same middle edges as the negative rhombohedron, $f(02\bar{2}1)$. Figure 11 was drawn by Mr. W. Valentine of the Sheffield Laboratory. It presents nothing new, and is practically identical with Figure 674 of von Bournon's *Traité de Minéralogie*, published in 1808. The figure is introduced in the present article, because by understanding its simple zonal relations, the same forms can be easily identified as they occur on a twin crystal to be described.

Figure 12 represents the development of two beautiful twin crystals in the Brush Collection, both occurring on the same hand specimen. The twinning plane is the unit rhombohedron, and the development is analogous to that of the butterfly twins from Egremont, Figure 10. A prominent feature of the

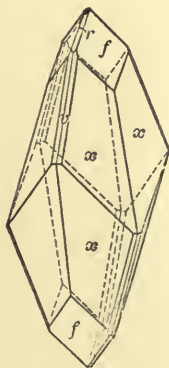


FIGURE 11.

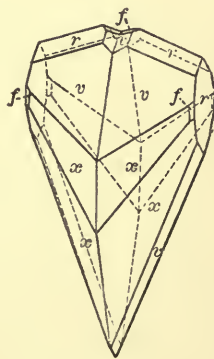


FIGURE 12.

twins is the vertical zone r, f , and x of the individual to the right, extending over the twinning plane to x, f , and r of the left-hand individual, and so on around the crystal. Thus with this method of twinning, four x faces, two in front and

two behind, form as it were a vertical prism, analogous to the prism formed by four faces of the scalenohedron *v*, Figure 4, when the flat rhombohedron $e(01\bar{1}2)$ is the twinning plane.

In Figures 4 and 12 the rhombohedral symmetry is not apparent, and the habit is like that of twin crystals of the monoclinic system, having the vertical faces *v* and *x*, respectively, as prisms and a pinacoid as twinning plane. The twin crystals represented by Figure 12 are so attached that only a portion of the lower *x* and *v* faces are visible.

ON THE CHEMICAL COMPOSITION OF TURQUOIS.

By S. L. PENFIELD.

(From Am. Jour. Sci., 1900, vol. 10, pp. 346-350.)

THROUGH the kindness of Mr. Ernest Schernikow of New York City, the writer has recently received a suite of turquoise specimens from deposits in Los Cerillos Mountains, New Mexico, and the Crescent Mining District, Lincoln Co., Nevada, and one fragment of exceptionally fine quality from the last-named locality was presented with the special request that it should be used for chemical analysis. The material was very fine-grained, of a beautiful robin's-egg blue color, and broke with a smooth fracture. A thin section of the material appeared translucent and almost colorless, and when examined under the microscope, the turquoise seemed to be perfectly uniform, showing no evidence of being made up of two substances, such, for example, as an aluminium phosphate, mixed with a copper salt as coloring material. The material was so fine-grained that no clue as to its crystallization could be made out other than that it acted somewhat on polarized light. The specific gravity, taken by suspension in the heavy solution, was found to be 2.791.

In considering the chemical composition of turquoise, it should be borne in mind that analyses have been made of only massive, cryptocrystalline fragments, and although they may be selected ever so carefully no such guarantee of the purity of the material can be given as when, for example, a well crystallized mineral is analyzed. In order to show, however, that turquoise is a material of nearly uniform composition, the new analysis is given below in connection with analyses made by other investigators. Analyses have not been included

which show a large proportion of foreign constituents other than silica. The analyses are as follows:

	I.	II.	III.	IV.	V.	VI.	VII.
	Lincoln Co., Nevada. Penfield.	Nichabour, Persia. Church.*	Karkaralinsk, Russia. Nicolajew.†	Fresno Co., California. Moore.‡	Los Cerillos, New Mexico. Three analyses by Clarke.§		
P ₂ O ₅	34.18	32.86	34.42	33.21	31.96	32.86	28.63
Al ₂ O ₃	35.03	40.19	[35.79]	35.98	39.53 ¶	36.88	37.88
Fe ₂ O ₃	1.44	2.45	3.52	2.99	. . .	2.40	4.07
CuO	8.57	5.27	7.67	7.80	6.30	7.51	6.56
H ₂ O	19.38	19.34	18.60	19.98	19.80	19.60	18.49
Insol.	0.93	. . .	. . .	. . .	1.15	0.16	4.20
X	. . .	MnO 0.36	. . .	. . .	CaO 0.13	CaO 0.38	. . .
	99.53	100.47	100.00	99.96	98.87	99.79	99.83
Sp. gr.	2.79	2.75	2.89	2.86		2.80	

In the new analysis the iron was found to exist wholly in the ferric condition, and therefore the iron in Church's analysis, given as FeO in the original article, has been calculated to Fe₂O₃ to agree with the observations of the present writer and other investigators.

It is evident from an examination of the foregoing analyses that turquoise is a material which is quite uniform in its chemical composition, so uniform in fact that it does not seem reasonable to consider it as an accidental mixture of an aluminium phosphate and a copper phosphate. The presence of the bivalent element copper, however, in somewhat variable amounts, is not so easily accounted for if we are to consider a copper phosphate as isomorphous with an aluminium phosphate. The small amount of iron is probably isomorphous with the aluminium, and it is to be expected that the iron phosphate would have little effect upon the color of the stone, for the hydrated ferric-phosphate, strengite, and the hydrated ferric-arsenate, scorodite, are both light-colored minerals. The idea that the iron is present as the hydrated oxide, limonite, can scarcely be entertained.

* Chemical News, x, p. 290, 1864.

† Kokscharow's Min. Russland, ix, p. 86, 1884.

‡ Zeitschr. Kryst., x, p. 247, 1884.

§ Amer. Jour. Sci., 1866, vol. 32, p. 212.

|| Given as 2.21 per cent FeO.

¶ Includes some Fe₂O₃.

An important factor to be taken into consideration in discussing the analyses is that the hydrogen in turquois is to be regarded as representing hydroxyl and not water of crystallization, for water is not expelled from the mineral at a low temperature; hence hydroxyl radicals may be considered as playing a part in the chemical composition of the mineral. Considering copper as an essential constituent of turquois and not as an impurity, two theories naturally suggest themselves: one, that the bivalent copper is isomorphous with, and replaces the bivalent aluminium-hydroxide radical $[\text{AlOH}]''$; the other, that the univalent copper-hydroxide radical $[\text{CuOH}]'$ is isomorphous with the univalent aluminium-hydroxide radical $[\text{Al}(\text{OH})_2]'$. The first of these ideas has led to no satisfactory solution of the problem; the second, however, reveals a constancy in the chemical relations of the mineral which can scarcely be regarded as due to accident. The relations in question are shown by combining aluminium and iron with two hydroxyls to form the groups $[\text{Al}(\text{OH})_2]$ and $[\text{Fe}(\text{OH})_2]$, respectively, and copper with one hydroxyl to form the group $[\text{CuOH}]$, and then finding the ratio between the phosphorus and $[\text{Al}(\text{OH})_2]' + [\text{Fe}(\text{OH})_2]' + [\text{CuOH}]' + \text{Excess of Hydrogen}$. The relations are shown by the ratios derived from the several analyses tabulated on the previous page, as follows:

		I.		II.		III.
P		0.482		0.462		0.484
$\text{Al}(\text{OH})_2$	0.686		0.788		0.702	
$\text{Fe}(\text{OH})_2$	0.018	1.450	0.028	1.332	0.044	1.320
$\text{Cu}(\text{OH})$	0.108		0.066		0.096	
H	0.638		0.450		0.478	

		IV.		V.		VI.		VII.
P		0.468		0.450		0.464		0.404
$\text{Al}(\text{OH})_2$	0.706		0.774		0.722		0.742	
$\text{Fe}(\text{OH})_2$	0.036	1.478	...	1.426	0.030	1.428	0.050	1.262
$\text{Cu}(\text{OH})$	0.098		0.080		0.094		0.083	
H	0.638		0.572		0.582		0.387	

Considering $[\text{Al}(\text{OH})_2]'$ + $[\text{Fe}(\text{OH})_2]'$ + $[\text{CuOH}]'$ + H as playing the rôle of a univalent radical R', the ratios of P : R in the several analyses are as follows :

I,	P : R = 0.482 : 1.450 = 1 : 3.01	
II, “	“ = 0.462 : 1.332 = 1 : 2.88	
III, “	“ = 0.484 : 1.320 = 1 : 2.73	
IV, “	“ = 0.468 : 1.478 = 1 : 3.16	
V, “	“ = 0.450 : 1.426 = 1 : 3.17	
VI, “	“ = 0.464 : 1.428 = 1 : 3.08	
VII, “	“ = 0.404 : 1.262 = 1 : 3.12	Average = 1 : 3.02

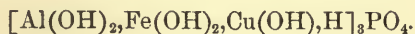
The author can vouch for the purity of the material analyzed by him, as far as it is possible to do so in the case of a cryptocrystalline mineral, and can also testify as to the accuracy of the analysis ; hence the very close approximation to the exact ratio 1 : 3, between the phosphorus and the sum of the univalent radicals plus the hydrogen, is very suggestive. The ratios in the other analyses approximate as closely to 1 : 3 as might be expected when the character of the material is taken into consideration, and the average of all the ratios is almost exactly 1 : 3. The ratio 1 : 3 is that of phosphorus to hydrogen in orthophosphoric acid, H_3PO_4 . Turquoise may therefore be regarded as a derivative of orthophosphoric acid in which the hydrogen atoms are to a large extent replaced by the univalent radicals $[\text{Al}(\text{OH})_2]$, $[\text{Fe}(\text{OH})_2]$ and $[\text{CuOH}]$. There seems to be no fixed ratio between the radicals $[\text{Al}(\text{OH})_2]$, $[\text{Fe}(\text{OH})_2]$ and $[\text{CuOH}]$, nor between the sum of the hydroxyl radicals and the hydrogen. In some cases, however, there is an approximation to the ratio 2 : 1 between the sum of the hydroxyl radicals and the hydrogen, as follows :

	$[\text{Al}(\text{OH})_2] + [\text{Fe}(\text{OH})_2] + [\text{CuOH}]$		H
II,	0.882	:	0.450 = 2 : 1.02
III,	0.844	:	0.478 = 2 : 1.13
VII,	0.875	∴	0.387 = 2 : 0.89

In cases like the foregoing, the composition of turquoise might be considered as a mixture of an aluminium

salt, $\text{H}[\text{Al}(\text{OH})_2]_2\text{PO}_4$, with the isomorphous molecules $\text{H}[\text{Fe}(\text{OH})_2]_2\text{PO}_4$ and $\text{H}[\text{CuOH}]_2\text{PO}_4$. The molecule $\text{H}[\text{Al}(\text{OH})_2]_2\text{PO}_4$ is equivalent to Clarke's* formula for "normal turquois," $2\text{Al}_2\text{O}_3 \cdot \text{P}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$, which he also writes $\text{Al}_2\text{HPO}_4(\text{OH})_4$. Adopting Clarke's suggestion that turquois contains very finely divided admixtures of iron and copper phosphates as impurities, and also his formula for the pure mineral (*normal turquois* of Clarke), Groth† expresses the composition as $\text{PO}_4\text{Al}_2(\text{OH})_3 \cdot \text{H}_2\text{O}$ but suggests, however, that the formula is perhaps $\text{PO}_4\text{H}[\text{Al}(\text{OH})_2]$.

In conclusion it may be stated that it is the author's belief that copper and the small amounts of iron are to be regarded as constituents of turquois, rather than as impurities. In support of this idea the constant occurrence of copper, as shown by all the published analyses, may be cited. Furthermore, finely pulverized turquois is only partially dissolved by boiling in a test-tube with hydrochloric acid; hence, if the material contained copper phosphate as an impurity, it would be expected that the copper phosphate would dissolve readily, leaving the basic aluminium phosphate as a pure white residue, while in tests which have been made the insoluble residues have remained blue from beginning to end of the experiments. Considering the existence in turquois of the univalent radicals $[\text{Al}(\text{OH})_2]$, $[\text{Fe}(\text{OH})_2]$ and $[\text{CuOH}]$, the composition of the mineral, as shown by the published analyses, may be expressed as a derivative of orthophosphoric acid, as follows:



The $[\text{Al}(\text{OH})_2]$ radical always predominates, but is not present in fixed proportion. Some analyses (II, III, and VII) conform closely to the formula $[\text{Al}(\text{OH})_2, \text{Fe}(\text{OH})_2, \text{Cu}(\text{OH})]_2\text{HPO}_4$.

Disregarding the iron, the calculated composition of turquois for two special cases of isomorphous replacements are given on the following page:

* Loc. cit.

† Tabellarische Uebersicht der Mineralien, 1898, p. 97.

[Al(OH) ₂ , Cu(OH), H] ₂ PO ₄ ; Al(OH) ₂ : Cu(OH) : H = 7 : 1 : 6.		Analysis I, page 366.	[Al(OH) ₂ , Cu(OH)] ₂ HPO ₄ ; Al(OH) ₂ : Cu(OH) = 12 : 1.	Analysis II, page 366.
P ₂ O ₅	34.64	34.18	32.13	32.86
Al ₂ O ₃	37.32	36.47 *	42.61	42.64 *
CuO	8.28	8.57	5.52	5.27
H ₂ O	19.76	19.38	19.74	19.34
. . .	Insol.	0.93	. . .	MnO 0.36
	<u>100.00</u>	<u>99.53</u>	<u>100.00</u>	<u>100.47</u>

Considering that turquoise is not a crystallized mineral, the agreement between theory and the analyses is certainly as close as could be expected.

* Includes the Fe₂O₃.

THE STEREOGRAPHIC PROJECTION AND ITS POSSIBILITIES, FROM A GRAPHICAL STAND- POINT.

By S. L. PENFIELD.

(From Amer. Jour. Sci., 1901, vol. 11, pp. 1-24, and 115-144.)

(NOTE. — In the original article of 54 pages, accompanied by four plates, the possibilities of solving a large variety of problems in spherical trigonometry by graphical methods are set forth. The problems may be those of crystallography, astronomy, geodesy, navigation, or of any nature whatsoever where spherical relations come into consideration. Simple methods are given for plotting spherical relations in the stereographic projection, and some instruments, called *Stereographic Protractors*, are described, by means of which the sides and angles of spherical triangles, thus plotted, may be measured. Only brief reference to this article is here given, including the introductory paragraphs and illustrations of some of the forms which the stereographic protractors may assume.)

INTRODUCTION. The results which are given in the present paper are the outgrowth of a desire on the part of the writer to simplify some of the processes of plotting and determining crystal forms. The whole subject of stereographic projection, as it has gradually unfolded itself to him during the past two years, has revealed so many possibilities, and seems so important and of such general interest, that it has been decided to present first a paper treating of the stereographic projection alone, leaving for a later communication its applications to special problems of crystallography.

As far as the mathematical principles of the projection are concerned, the writer lays claim to no new facts. The projection is treated, in more or less detail (usually very briefly), in most text-books of crystallography, and instructions are

given for making stereographic projections. The processes recommended, however, are generally tedious, and one of the objects of the present paper is to indicate how projections may be constructed easily and very accurately. Moreover, no mathematical formulas nor equations have been used in developing the subject, neither have tables been employed other than one of natural tangents for calculating a certain scale. The principles of the projection, as set forth in this article, are absolutely exact; while the errors involved in solving problems by graphical methods are dependent upon one's ability to locate points and read scales correctly, the errors generally diminishing as the size of the projection increases. It is also true of numerical calculations that the processes are limited. Given exact data, results accurate to the minute or to the second are obtained according as four-place or seven-place logarithm tables are employed; while for some very exact geodetic computations, where small fractions of a second must be taken into consideration, ten-place logarithm tables are at times made use of. The advantages of graphical methods over numerical calculations are numerous, and are fully appreciated by engineers and others who deal extensively with measurements and practical results derived therefrom.

The writer would be one of the last to claim that numerical calculations can be dispensed with, yet he contends that, for a large number of problems, especially those where the data are not very exact, results obtained by graphical methods are in every way as serviceable as those secured by calculation. Then, too, it is possible to make computations by graphical methods wholly without the use of formulas and tables, and the processes can be carried out intelligently by persons who have had no special mathematical training, provided only that they have an appreciation of measurements expressed in terms of degrees and fractions. Many advantages to be derived from the use of the stereographic projection will naturally suggest themselves during the course of this paper. In subsequent paragraphs some of these advantages will be set forth,

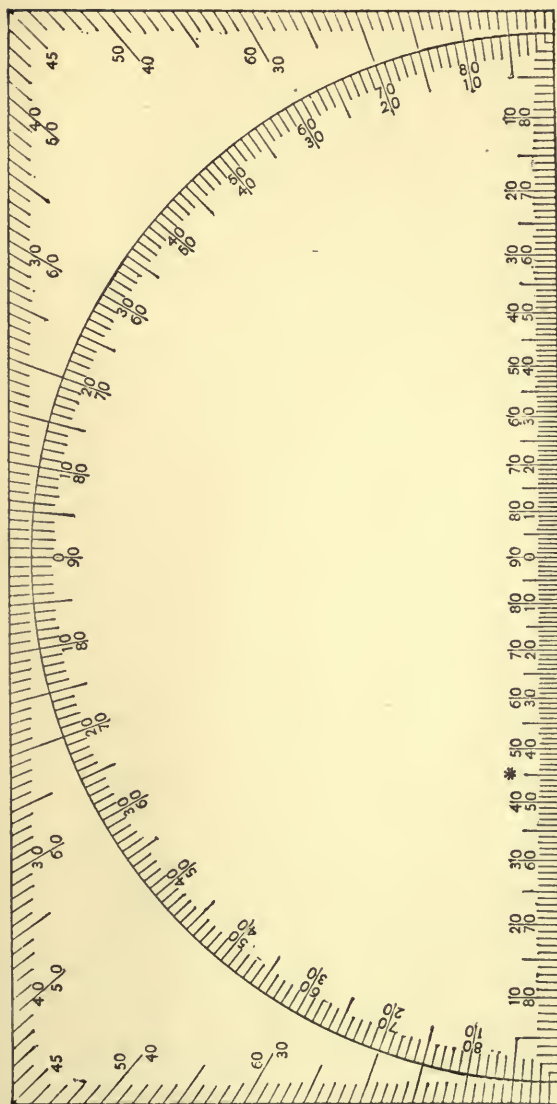
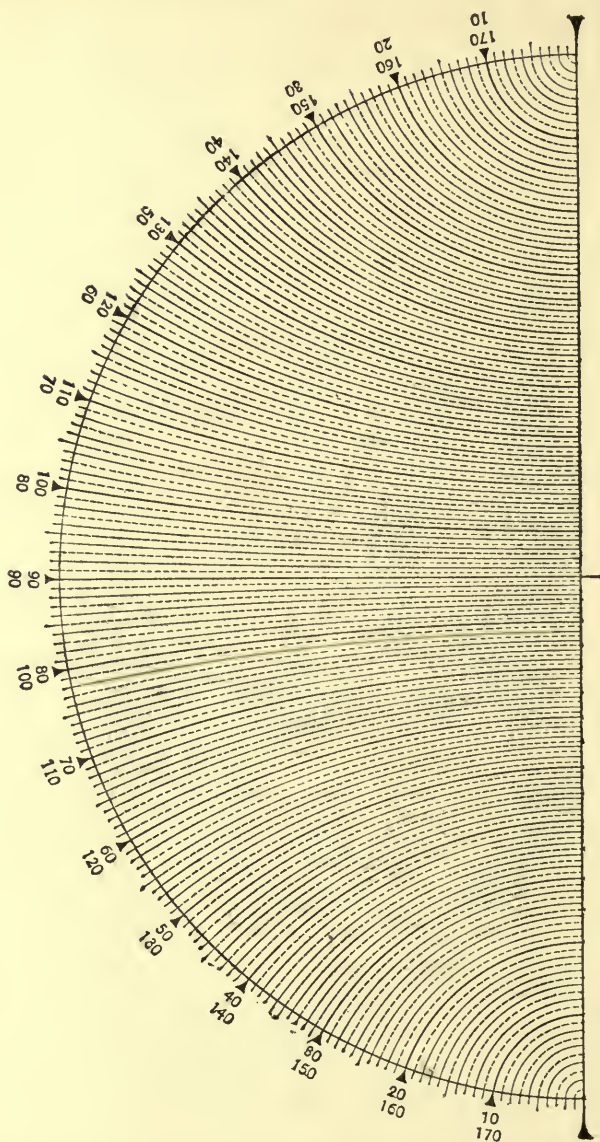


FIGURE 1.

PROTRACTOR NO. 1, FOR PLOTTING STEREOGRAPHIC PROJECTIONS.

and results obtained by plotting will be given, in order that an idea of the accuracy of the method may be obtained.

The Stereographic Protractors.—These may be made of



Patented Feb. 5, 1901.

FIGURE 2.

STEREOGRAPHIC PROTRACTOR No. II, FOR MEASURING THE ARCS OF GREAT CIRCLES.

various sizes to suit the requirements of different kinds of work, and they have this peculiarity; that they must be based

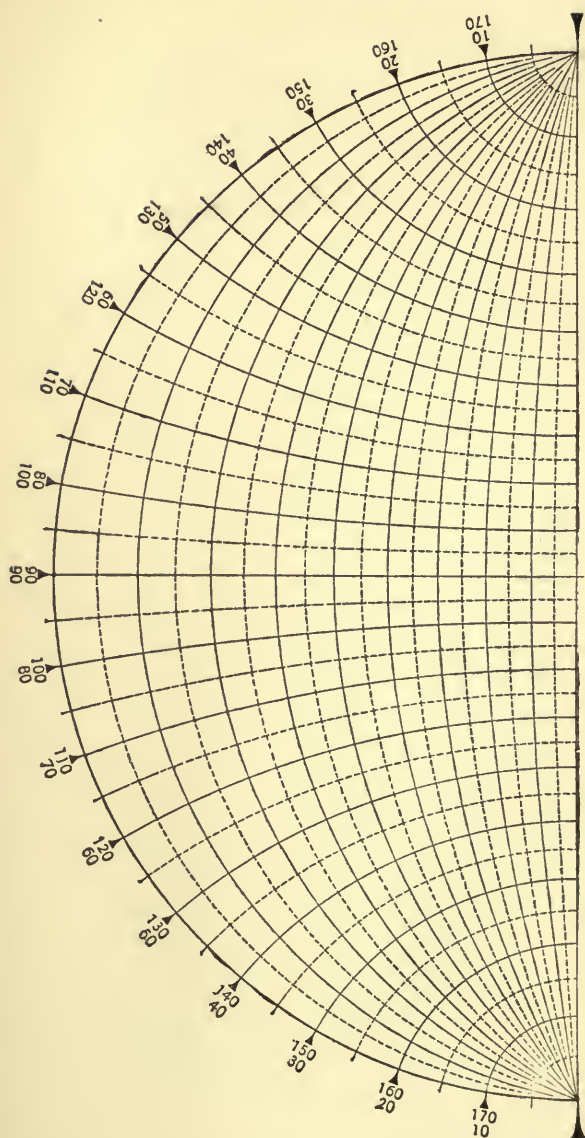


FIGURE 3.
STEREOGRAPHIC PROTRACTOR No. III.

Patented Feb. 5, 1901.

upon a circle of the same size as that employed in making the stereographic projections with which they are to be used.

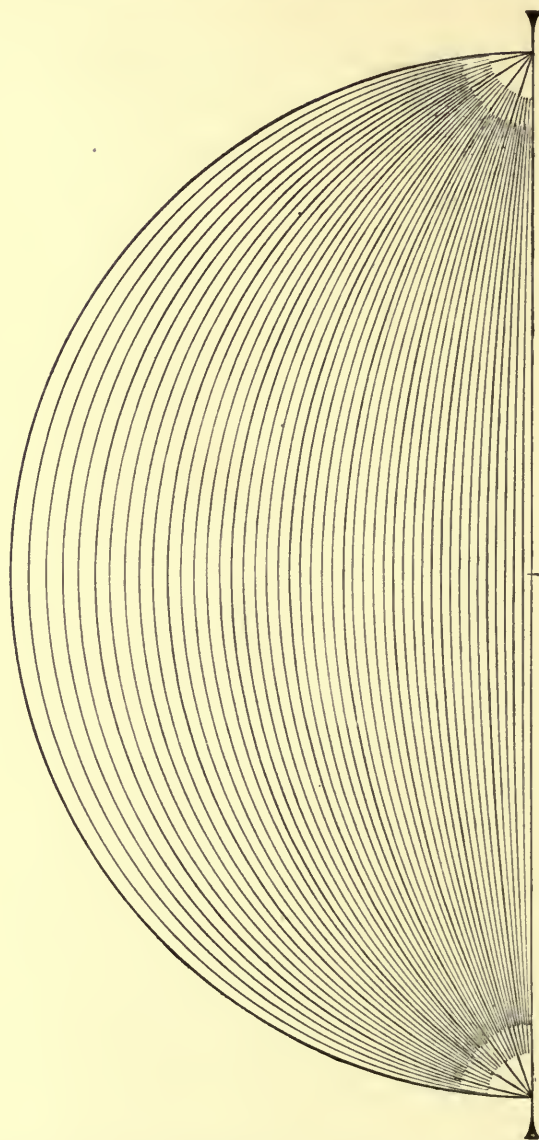


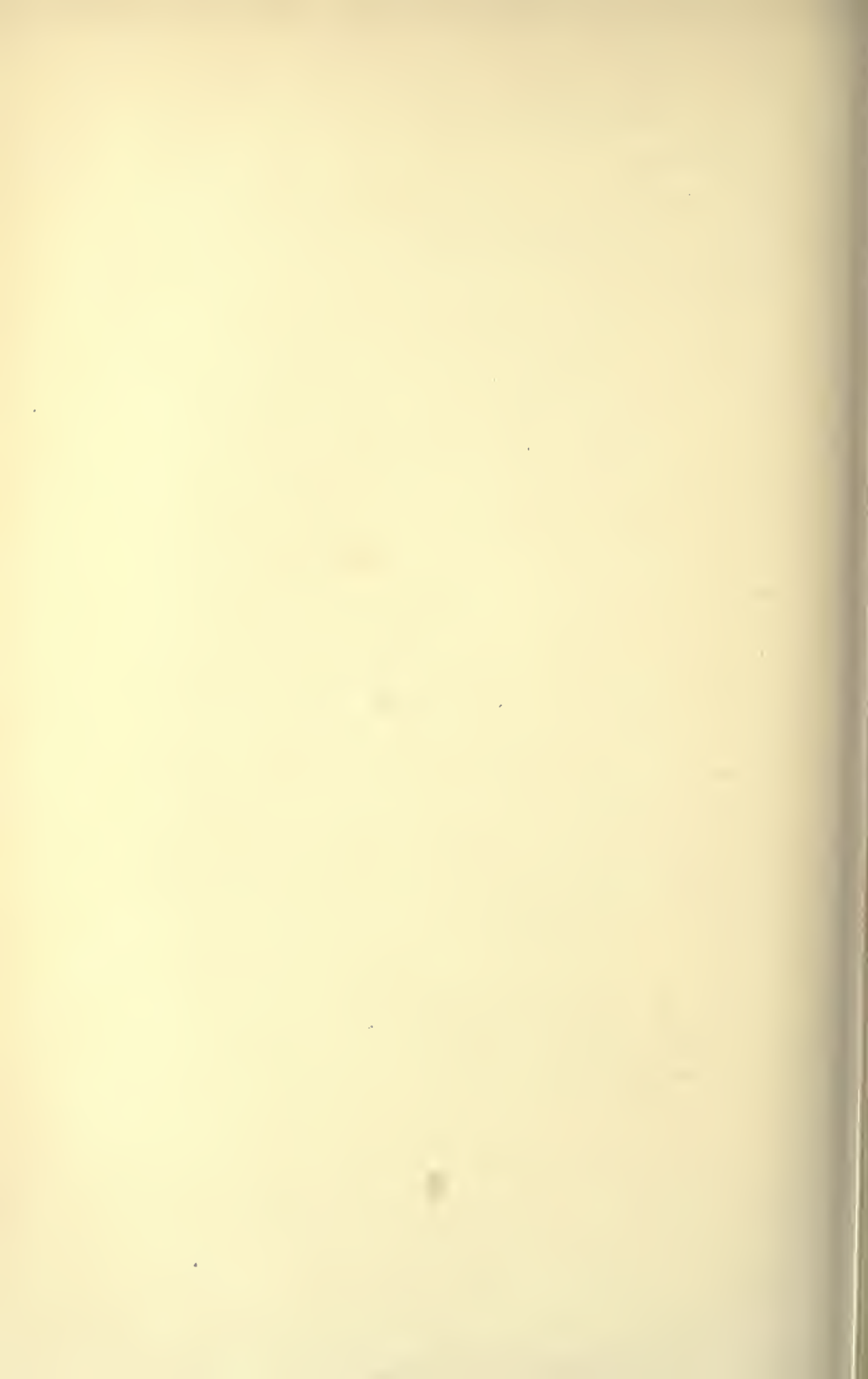
FIGURE 4.
STEREOGRAPHIC PROTRACTOR NO. IV

Patented Feb. 5, 1901.

The ones shown by Figures 1 to 4 are based upon a circle of 14 cm. diameter.

Protractor No. I, Figure 1, may be printed on card or engraved on metal, and is used for plotting stereographic relations. It has a scale giving stereographically projected degrees on its diameter or base line, otherwise it is like an ordinary protractor.

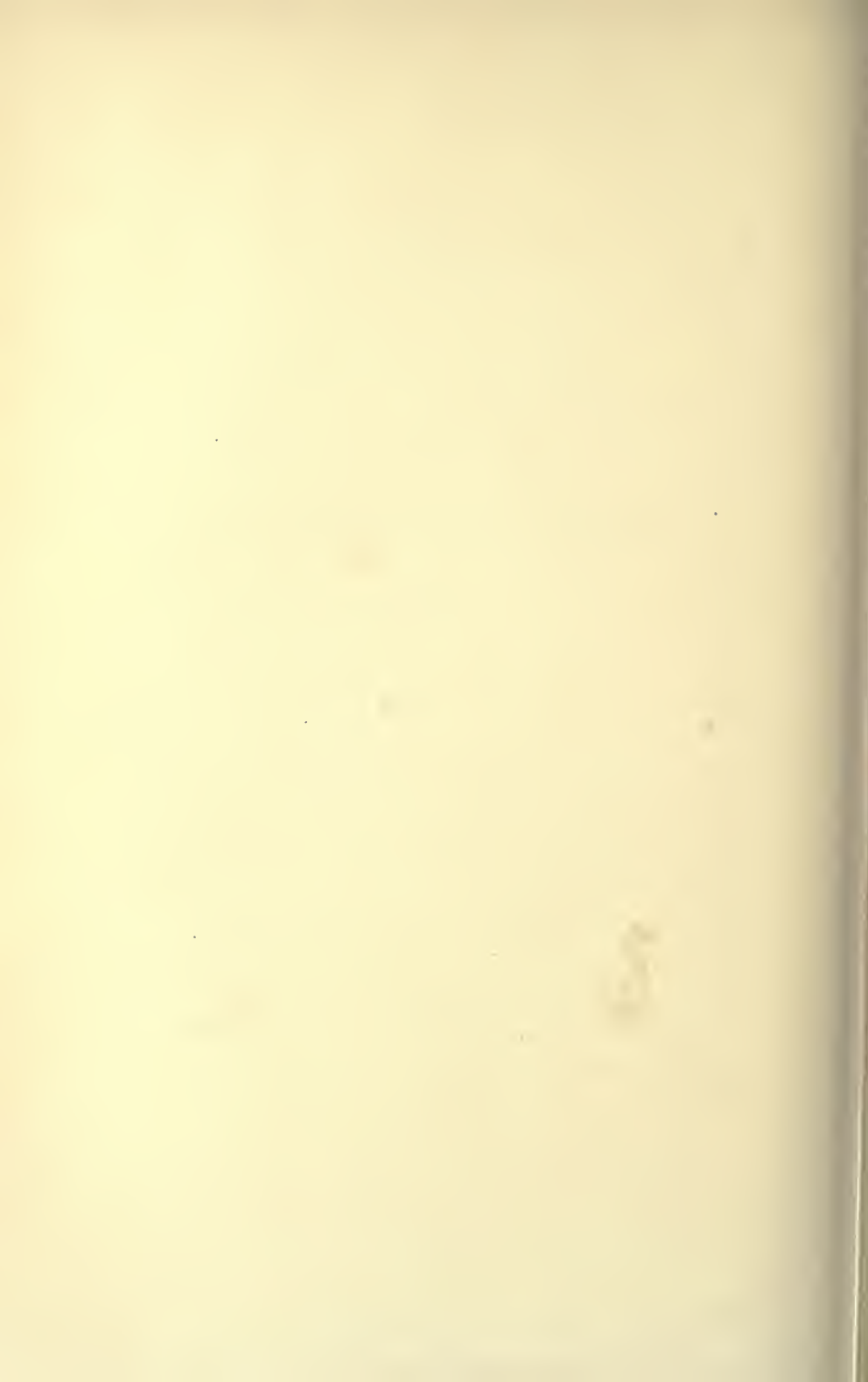
Protractors Nos. II, III, and IV are best printed or engraved on transparent celluloid. No. II, Figure 2, consists of a series of stereographically projected small circles, every tenth degree of the series being numbered. When this protractor is centered and properly adjusted over a stereographic projection the distance apart of any two points may be told by noting their position with reference to the stereographically projected small circles of the protractor. Protractor No. III, Figure 3, gives a combination of small circles and great circles. By means of it approximate solutions of problems (to within a degree of the truth) may be made. Protractor No. IV, Figure 4, gives a series of stereographically projected great circles. By centering it upon a projection and turning, the direction of the great circle passing through any two points may be determined. For a complete description of the protractors and their uses, and suggestions concerning the applications of the stereographic projection to accurate map-making the reader is referred to the original article. The protractors, various appliances for facilitating the construction of accurate stereographic projections, and extra copies of the original article may be secured at the Yale Co-operative Corporation's Store on the College Campus.



PART II.—PETROGRAPHY

EDITED BY

L. V. PIRSSON



HISTORY OF THE PETROGRAPHICAL DEPARTMENT.

By L. V. PIRSSON.

THE sciences of Mineralogy and Petrography are most intimately related. Since Mineralogy is dependent on chemistry on the one hand and on Physics and Mathematics on the other, so Petrography rests on Mineralogy and Chemistry on one side and on Geology on the other. It sprang indeed from Mineralogy and in its earlier days before the application of Chemistry and Geology brought forth those general laws and principles which give it position as an independent science, it was a branch of Mineralogy, microscopical mineralogy in fact.

Thus we cannot, in one sense, positively state when Petrography began at Yale. From the days of the elder Silliman, through the labors of J. D. Dana, of G. J. Brush, and of their assistants and pupils in the laboratory, the ever increasing sum of accumulated mineralogical knowledge which has made the name of Yale famous the world over in this branch of human knowledge has had beyond doubt an influence on the development of the science.

But so far as the writer knows, the first investigation of a rock and its constituents from the petrographic point of view was made in 1872 by Professor E. S. Dana and published in the American Journal of Science. He was at that time a student in the laboratory and the investigation was made on material forwarded by Prof. C. H. Hitchcock. This resulted in the founding of a new rock type called *Ossipyte*. This paper, from its historical interest, is reprinted as the first of those given in this chapter. After this, during the course of his studies in Europe, Dana devoted considerable time to microscopical petrography, which was then just beginning to

attract the earnest attention of geologists and mineralogists, since it was perceived that the microscope would lend them powerful aid in the prosecution of their investigations.

As a result of these studies he became interested in petrography and read in 1875, not long after his return from Europe, a paper on the "Trap Rocks of the Connecticut Valley," before the American Association for the Advancement of Science, an abstract of which appeared in their proceedings and was also published in the American Journal of Science. This can truly be said to be the first important memoir in this science published in this country and to be the forerunner of the long series of able investigations crowned with brilliant results which have given American petrographers the commanding position they hold to-day.

In his work on the trap rocks of the Connecticut sandstone area, Dana was aided on the chemical side by G. W. Hawes, assistant in the mineralogical laboratory to Prof. G. J. Brush. Undoubtedly this work stimulated the interest of Hawes in this branch of science and led him to further researches in petrography; the titles of the papers giving the results of these researches are seen in the appended bibliography. The lack of training on the side of microscopical petrography is seen, however, in the earlier work of Hawes, especially for instance in his paper on the greenstones of New Hampshire and their organic remains, in which certain structures common to such rocks were mistaken for fossils and therefore held to indicate their sedimentary origin.

Feeling the need therefore of better training in this line, Hawes went abroad for study under well known German specialists.

The effects of this showed speedily in the work he then produced and important papers, the results of careful and patient investigations along the line of modern petrography, began to issue from his pen. Some of these short articles, from the importance of the results announced in them, have become classics in the science and two of them which hold such a place have been reprinted in this portion of this work.

Hawes, however, left Yale in 1880 to go to the National Museum and his early death soon after deprived the science of one of its most sincere, able, and earnest workers. A short obituary of Hawes, taken mostly from notices which appeared at the time of his death, together with a bibliography of his works, is added to these reprints of his papers.

After the departure of Hawes for Washington, an interval of some years elapsed before petrographic work was again definitely taken up at Yale, though occasional analyses of rocks by Penfield and an important paper on the Hawaiian lavas by E. S. Dana based on material collected by his father J. D. Dana during his visit to the Hawaiian Islands in 1887, appeared during this period.

In 1892 the writer who had prepared himself by study under Rosenbusch at Heidelberg and Fouqué and Lacroix at Paris, was appointed instructor in lithology in the Scientific School and petrography was placed on a definitely recognized basis. It is often difficult to start a new branch of the descriptive sciences at a new institution, but generally easy at an old and long established one like Yale, where material of all kinds naturally accumulates. Thus through the previous care and interest of Brush, Penfield, and the two Danas, the writer was enabled to begin this branch of science under most favorable conditions as regards collections, library, etc.

From that time down to the present a considerable amount of petrographic work has been done and the collections, library, apparatus and the number of students have increased to such a degree that it is no longer possible to occupy jointly the same laboratory with the mineralogical department. Other quarters have therefore been provided and now (1900) petrography finds itself at home in independent quarters as a well equipped sub-department.

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ON THE COMPOSITION OF THE LABRADORITE ROCKS OF WATERTOWN, NEW HAMPSHIRE.

By E. S. DANA.*

(From Amer. Jour. Sci. (3), vol. 3, pp. 48-50.)

THE specimens of labradorite rock which I have had under examination were obtained by Professor Dana last September, on a visit with Professor Hitchcock to the locality at Waterville, New Hampshire.

There are two distinct varieties, both mentioned by Professor Hitchcock in the preceding article. The first is a dark-colored rock, consisting in the main of a triclinic feldspar, together with small yellowish grains of a mineral which Professor Brush in a blowpipe examination referred to chrysolite. A careful examination reveals to the eye also some minute grains of a magnetic ore of iron, and also a very little of a black mineral, probably hornblende.

The feldspar has a dark smoky color, without iridescence, and is beautifully striated. It fuses B. B. with somewhat less readiness than ordinary labradorite, and is scarcely attacked by acids. It was picked out as carefully as possible, and analyzed with the following result:—

* So far as known, this is the first petrographic study of this rock type consisting of labradorite and olivine. It is here definitely determined, described and named. The Germans have called such rocks "forellenstein," and this has been turned into "troctolite" by Bonney in 1885, but ossipite has priority, and should stand. — EDITOR.

	I.	II.	III.	Mean.
SiO ₂	51.04	51.02	. . .	51.03
Al ₂ O ₃ (TiO ₂)	26.34	26.07	. . .	26.20
Fe ₂ O ₃	4.79	5.13	. . .	4.96
CaO	14.09	14.23	. . .	14.16
Na ₂ O	. . .	. . .	3.44	3.44
K ₂ O	. . .	. . .	0.58	0.58
				100.37

The large percentage of iron (determined volumetrically) had not been expected, as the eye had failed to detect any impurities in the fragments selected for analysis. Some very thin pieces were afterward examined under the microscope; and by this means it was found that even the clearest pieces contained very minute grains of an iron ore, from $\frac{1}{50}$ th to $\frac{1}{200}$ th of an inch in diameter, which were strongly attractable by the magnet. Microscopic dark specks less than $\frac{1}{10000}$ th of an inch in size were also observed and at first referred to the same cause; but on magnifying them 800 diameters, it was concluded that they were air-cavities in the structure of the feldspar, and not any foreign matter. The peculiar dark-smoky color of the rock is doubtless to be explained by the presence of these particles of iron ore.

This magnetic iron ore, a sufficient amount for the test having been picked out by the magnet, gave a decided reaction for titanous acid. It is, therefore, probably a very magnetic titanous iron, though it was impossible to obtain a sufficient amount of the substance for a quantitative determination of the titanium. The absence of any octahedral faces or isometric structure in the grains is in favor of their being titanous iron.

In consequence of this impurity, which could hardly be removed, it is not to be expected that the analysis should give a satisfactory formula; the result obtained, however, is sufficient to prove that the feldspar is unquestionably labradorite.

The analyses of the mineral, supposed to be chrysolite, occurring in yellow, glassy grains, afforded:—

	I.	II.	Mean.
SiO ₂	38.82	38.88	38.85
Al ₂ O ₃	tr.	tr.	tr.
FeO	28.00	28.15	28.07
MnO	1.12	1.36	1.24
MgO	30.88	30.36	30.62
CaO	1.26	1.60	1.43
	<u>100.08</u>	<u>100.35</u>	<u>100.21</u>

The oxygen ratio of the bases and silica afforded is nearly 1:1, and of the iron and magnesia about 1:2; whence the formula $(\frac{1}{3}\text{Fe} + \frac{2}{3}\text{Mg})_2\text{Si}$. This is then a chrysolite containing an unusually large percentage of iron (here a constituent of the mineral, and not owing to the presence of impurities). The amount of iron is not strange, considering the fact, that the rock contains diffused throughout it so much free iron ore.

This chrysolite has the same ratio deduced for hyalosiderite, but still differs widely in fusibility and other characters. It is in fact a true chrysolite in all respects, while hyalosiderite is a doubtful compound, probably owing its fusibility in part to the potash present. B. B., the chrysolite, is nearly infusible.

In two samples of this labradorite rock, obtained with care, so as to represent the average composition, 1.70 and 1.94 (mean 1.82) per cent of MgO were obtained, which would give 5.94 as the percentage of the chrysolite in the whole.

This rock, consisting of labradorite with grains of chrysolite disseminated through it, is one not previously described. Professor Hitchcock has proposed to call it *Ossipyte*, after the name of the tribe of Indians (the Ossipees) formerly inhabiting that region.

The second variety of the rock (for position, etc., see page 45, 16th line from foot) presents quite a different appearance. The feldspar, here in large, cleavable masses, often half an inch long, and a dark mineral, the angle of whose cleavage planes proves it to be hornblende, form the mass; together

with these are associated a magnetic titanite iron in segregated masses of some size, very little of a dark brown mica, and a green mineral, probably epidote. There is no chrysotile.

This feldspar has a grayish-white color, is destitute of iridescence, and only careful searching reveals any striations.

Two analyses afforded: —

	I.	II.	III.	Mean.
SiO ₂	52.15	52.36	. . .	52.25
Al ₂ O ₃	27.63	27.39	. . .	27.51
Fe ₂ O ₃	1.09	1.07	. . .	1.08
MgO	0.92	1.06	. . .	0.99
CaO	13.10	13.45	. . .	13.22
Na ₂ O	. . .	. . .	3.68	3.68
K ₂ O	. . .	. . .	2.18	2.18
				100.91

Both analyses show that the labradorite of the region is remarkable for the large proportion of lime present.

GEORGE W. HAWES.

GEORGE W. HAWES was born December 31, 1848, at Marion, Indiana. His parents died when he was very young, and his early life was spent at Worcester, Mass. In 1865 he entered the Sheffield Scientific School, and remained till the end of his Junior year, when he left to go into business in Boston. His taste for science, however, led him to abandon a business career, and he again entered the Sheffield School, and was graduated with the class of 1872. During the college year 1872-73 he was private assistant to Prof. S. W. Johnson in the chemical laboratory, and from 1873-78 he was assistant and instructor in mineralogy and blowpipe analysis in the Scientific School. The summer of 1878 he spent at Breslau in the study of microscopical petrography under Prof. A. von Lasaulx. He returned to New Haven in the fall, and again became instructor in mineralogy, and in the spring went abroad the second time for further study. The following year was spent in the study of mineralogy and crystallography at Bonn, under Prof. G. vom Rath, and in petrography at Heidelberg, under Prof. H. Rosenbusch. At the latter place he took the degree of Ph.D. On his return to this country he again took up his old place at New Haven, but at the end of the year (1880) he accepted the position of Director of the Geological Department of the National Museum at Washington, which he held up to the time of his death from consumption, June 22, 1882.

Hawes was one of the earliest workers in petrography in this country, and had he lived he would undoubtedly have been one of the most distinguished of his time. He had fitted himself by years of careful study to do the best of work in his chosen science, and the quality of his work is seen in

his published papers. His most important work is his report on the mineralogy and lithology of New Hampshire, an octavo volume of 262 pages, embodying the results of considerable field work and the preparation and study of several hundred thin rock sections. At the time of his death he was engaged in a report on the building stones of the United States, a work completed and published later by his successor, Prof. G. P. Merrill of Washington.

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ON A GROUP OF DISSIMILAR ERUPTIVE ROCKS IN CAMPTON, NEW HAMPSHIRE.

By GEORGE W. HAWES.*

(From Amer. Jour. Sci. (3), vol. 17, pp. 147-151.)

AMONG other results of the petrographical studies made by me under the direction of the New Hampshire State Survey,† I have shown that the rocks of the dikes, abundantly scattered through the White Mountains, are very diverse in composition and in mineral constituents. Independently of the results of decomposition, which has in many cases widened original differences, rocks which to the eye appear identical are often found, on microscopic examination, to be fundamentally different; and the rocks of closely adjoining dikes not infrequently have nothing in common save their geological position. This feature is quite striking, especially when considered in connection with the uniform character of the eruptive rocks in some adjoining regions. To illustrate it I have made a study of a small group of dikes in Campton where this diversity is very well exhibited.

The Livermore Falls are in Campton, but they are only two miles distant from the larger and more accessible town of Plymouth. The Pemigewassett river has here cut a gorge through a hill, and in the walls of this gorge the eruptive dikes are very conspicuous. The gorge is not long, and the dikes, five in number, are all embraced in a portion of it which is little more than a hundred yards in length.

* This was the first description, under the name of "diorites and diabase," of the interesting and important group of rocks to which Rosenbusch has given the name of Camptonite, from this, the original locality. — EDITOR.

† Geology of New Hampshire, Hitchcock, part iv, Mineralogy and Lithology.

Attention was called to these dikes in 1837, by Prof. O. P. Hubbard of Dartmouth College.* His description of them is accompanied by a picture of the gorge, which shows their forms and relative position; but as the rocks could only be identified by microscopic examination, he did not attempt to classify them.

The rock through which the dikes intrude is mica schist, which presents its usual diversities, caused by variation in the proportion of the essential ingredients and the presence of accessories. The strike is northeast, and the dip is variable. These rocks are considered to be as old as the Silurian, and Professor Hitchcock regards them as still older.

The five dikes cut the schist almost at right angles; all are nearly vertical and parallel to one another. A bridge has been built across the gorge from which all the dikes can be seen except the one directly under the bridge. From their position with reference to the schists, it is inferred that the fractures resulted from the action of the same forces acting in the same way. Yet among these five dikes there are found four very well-distinguished rock species. I will describe these rocks in the order in which they occur, beginning with the one highest up the stream.

Dike No. 1 is seen only upon the left of the stream. It is about three feet wide; the rock is black in color, compact, and apparently nearly homogeneous. The study of some thin sections indicates that it is a *diabase*. It was originally a mixture of augite, a triclinic feldspar and titanite iron, but all its ingredients are partially altered. The augite is in process of alteration into hornblende; some of its grains being still intact, some being partially and others wholly altered. The feldspar is more or less changed, but shows its polysynthetic character throughout. The titanite iron oxide is extensively altered into the grayish white product that is called leucoxene. Minute apatite crystals are seen in the section. Calcite, as a decomposition product, fills cavities that are apparently made by the removal of some

* Amer. Jour. Sci. (1), vol. xxxiv, p. 105.

other mineral; these cavities are also often partially filled with analcite, which has a cubic cleavage and exerts a very feeble action upon polarized light. The analyses of all the rocks described are placed together on a subsequent page.

Dike No. 2 is eight feet wide. The rock is black in color, and is composed of a very fine, almost homogeneous ground-mass, in which small black shining crystals are porphyritically developed. The thin sections indicate that this is *diorite*. It is a mixture of hornblende, a triclinic feldspar, and titanite iron oxide. The large crystals are of hornblende; it is here an original product, and has not resulted from the alteration of pyroxene, as in the last case, since its well-formed crystals are developed in the common hornblendic forms. Many of them are twin crystals, the twinning plane being, as usual, parallel to the orthopinacoid. Both the large porphyritic crystals and the small ones in the ground-mass are fresh and unaltered. The feldspar is in part fresh and in part somewhat altered. The basic nature of this rock, as of the last, indicates that the feldspar is a variety low in silica, but its species cannot be determined by optical means. The iron oxide is quite abundant, and in part well crystallized. Sometimes a large opaque hexagonal section is met with which is probably menaccanite. The rock contains a little apatite. Calcite, some zeolitic mineral of an undetermined species and a little chlorite exist as decomposition products.

Dike No. 3 is ten feet wide, and is filled with a massive rock fine in texture and white or grayish in color. When a section cut from a white specimen is examined, the rock is seen to be composed largely of small, quite well-defined orthoclase crystals. The meeting of these forms angular corners, that are for the most part filled with lime and iron carbonates and chlorite, though some are filled with quartz. In sections from the darker specimens it becomes evident that the aggregate in the angles is a decomposition product, for remnants of a dichroic green mineral, which is probably hornblende, are left there. It contains in addition some

magnetite, and some specimens show a little pyrite. The rock is a very fine-grained syenite similar to those which occur in different parts of the State.

Dike No. 4 is about a hundred feet from No. 3, but is identical with it in all respects. Dike No. 3 separates into two branches in the middle of the stream, and forms two dikes in an island there situated, and it is not improbable that No. 4 may unite with it at some point.

Dike No. 5 is about seventy-five feet from No. 4. It is very narrow, being only about a foot wide, but it has several branches as wide as itself which unite with it at acute angles. This again, like No. 2, is composed of a fine-grained ground-mass in which larger crystals are developed, but when the sections are examined it is found to be an *olivine diabase*. The porphyritic crystals are in part perfectly formed augite crystals, and in part well-formed olivine crystals which are mostly changed to serpentine. The finer portion of the rock is composed of augite, a triclinic feldspar, titanite iron and minute brown dichroic crystals of hornblende. Some small amygdaloidal cavities were observed containing sphærosiderite, calcite, and analcite.

In these five closely-adjointing dikes there are, therefore, four very different kinds of rocks. Selecting specimens as fresh as possible from the different dikes, I analyzed them with the following results:—

	Diabase. Dike No. 1.	Olivine Diabase. Dike No. 5.	Diorite. Dike No. 2.	Syenite. Dikes Nos. 3 and 4.
Silica	41.63	42.77	41.94	58.25
Alumina	13.26	14.06	15.36	18.22
Iron sesquioxide . . .	3.19	2.72	3.27	1.07
Iron protoxide	9.92	8.34	9.89	5.96
Manganese protoxide	0.27	0.15	0.25	0.10
Titanium dioxide . .	3.95	2.35	4.15	tr.
Lime	8.86	11.47	9.47	1.51
Magnesia	7.31	9.72	5.01	tr.
Soda	2.49	1.89	5.15	4.19
Potash	3.32	1.43	0.19	5.59
Carbon dioxide	5.20	1.62	2.47	4.75
Water	1.35	2.74	3.29	0.85
	100.75	99.26	100.44	100.49

Though I have mentioned the existence of decomposition products, they are present only in minute quantities; and as in these very compact rocks the new compounds must have been formed from the old, I think the above analyses represent very nearly the original composition of the rocks, with, however, the addition of the water and the carbon dioxide.

Between the light and dark colored rocks there is a wide difference, which indicates that the reservoirs from which they were ejected contained fused material of very different compositions. The black rocks are nearly alike in composition, but their differences are such as might account for the variation in mineral constituents. The quantivalent proportion of the sesquioxides to the protoxides is considerably higher in the diorite than in the diabases, and this is a condition favorable to the formation of diorites, as shown by the higher percentage of alumina usually found in the hornblende of eruptive rocks. The larger percentage of magnesia may have favored the formation of olivine in one diabase and not in the other. But the presence of compact and porphyritic materials in different dikes, though of nearly the same composition, indicates different conditions of cooling and crystallization, and these may also have been a cause of the mineral distinctions.

In the adjoining Connecticut Valley the red sandstones are cut by numerous dikes. Many of these rocks and others geologically related have been microscopically examined by E. S. Dana,* and some were analyzed by myself.† It was shown that these large dikes which are so characteristic of the Mesozoic red sandstone of this coast are, wherever found, essentially uniform in composition and mineral constituents. They are compounds of labradorite, augite, and magnetite, and vary only in the extent of their alteration. Professor Dana has concluded from this uniformity and their wide distribution over the Atlantic slope from Nova Scotia to North Carolina, that the dikes reach to profound depths.

* Amer. Jour. Sci., III, viii, 390.

† Ibid., III, ix, 185.

It is most probable that the large and small dikes that are so common among the crystalline rocks of New Hampshire, occupy fissures which were made during the elevation of the mountains. In the process of elevation, variable conditions must have been introduced in the strata at different places and times, on account of the conversion of mechanical work into heat, as has been shown by Mallet and others, and this would have modified the depth at which fused materials would be found beneath the surface. If partial crystallization took place before eruption, as in the case of many modern volcanic rocks, very variable conditions might also have been introduced at different times for their solidification. The Mesozoic sandstones referred to do not occupy a position that indicates a great strain upon the earth's crust at the time of fracture, but are found in areas of gentle subsidence, and the uniformity in the dikes that characterize these regions, when compared with the diversity in the dikes of the mountain region of New Hampshire, is as striking as is the contrast in the geological features of these two areas of eruption. A sinking of the earth's crust might result in profound fractures which would reach to the homogeneous zone beneath the sedimentary formation. The crushing attendant upon elevation might fuse sedimentary deposits at various depths, and produce fissures that would be filled with the most diversified material.

THE ALBANY GRANITE, NEW HAMPSHIRE, AND ITS CONTACT PHENOMENA.

By GEORGE W. HAWES.

(From Amer. Jour. Sci. (3), vol. 21, pp. 21-32.)

IN the studies that have been directed to the end of discovering the nature and origin of our great granitic masses, the contact phenomena have received but little attention. The application elsewhere of the modern methods of lithological research to the rocks upon the limits of granitic masses has, however, been fruitful in developing facts of geological interest. The study which I present indicates that no more striking phenomena have been observed anywhere than those which are found upon the boundaries of one of the New Hampshire granitic masses. These phenomena have additional interest since they occur in a region of highly crystalline schists, which usually are not susceptible to influences of this nature. In the Vosges, for example, the granites, which have produced the most marked and wide-reaching effects upon clay slates, have had no influence upon the crystalline schists which they have intersected.* As the New Hampshire granite here considered exhibits very striking modifications in character, dependent upon the neighborhood of the contact, and as a spot was found where the arrangement of the rocks is favorable for a careful consideration of the effects of the contact both upon the schists and the granite, I have investigated these rocks with a view of presenting this study as a contribution to White Mountain Geology.

The line of contact between the Albany granite and an area of argillitic mica schist crosses Mount Willard in the

* H. Rosenbusch, *Abhandlungen zur geologischen Special Karte von Elsass-Lothringen*, Bd. I, Heft II, p. 89.

Crawford Notch. The normal rocks with their contact modifications are familiar to many of our geologists. The beauty of the natural scenery, combined with the geological interest, has attracted many to this spot, and these rocks have accordingly had frequent mention. For the opinions in regard to the nature and origin of the granites at this point, and the interpretation of the effects that are due to the contact, I refer to the second volume of the Report on the Geology of New Hampshire, by Professor C. H. Hitchcock. As the relation of these peculiar rocks to one another, and the nature of the changes that they have undergone can, however, be discovered only by chemical and microscopical study, it is neither necessary nor just to submit to critical consideration the opinions formed without the aid of these methods.

Although Mount Willard is but a small mountain, several of the most characteristic New Hampshire granites take part in its composition. In this paper it is proposed to confine the attention to the Albany granite,* which forms an immense mass covering many square miles to the west, but which crosses Mount Willard in the form of a dike about three hundred feet wide. The Conway granite, a coarse-grained, biotite granite, forms the hanging wall, and argillitic mica schists form the foot wall of this dike. Mount Willard presents a bold cliff nearly a thousand feet high toward the south, and the contact lines of these three rocks run diagonally across this cliff, exposing themselves most favorably for study and observation. We have here, then, a small and narrow granitic mass which is connected with a great mass, and this forms in a modified way a parallel to the celebrated "Bodegang," which is a small narrow dike that connects the Ramberg and Brocken, two granite mountains in the Harz, the phenomena connected with which have been described by Lossen.†

The Albany granite is a very distinctly and definitely

* So named by Professor Hitchcock on account of its extensive development in Albany, N. H.

† Zeitschr. d. d. Geol. Ges., 1874, p. 856.

characterized rock. It is called by Hitchcock the spotted or trachytic granite.* In all its areas it has the same peculiar appearance due to the development of Carlsbad twins of orthoclase with rounded contours, in a gray fine-granular aggregate of granitic minerals, which are said to form a mixture resembling pepper and salt. Whether red or white, it is equally characteristic in appearance, and from its extensive development it is to be considered as one of the important granitic masses of New England.

Nor in its microscopic characters is this granite less characteristic. Its twin crystals of feldspar in polarized light are seen to have the peculiar structure of perthite, and consist of interlaminated orthoclase and albite.† Individual grains of a triclinic feldspar are often seen. The quartz is in formless grains and possesses the usual fluidal inclusions, and the position in angular corners due to the order of crystallization. The chief accessory is hornblende, which is black in the rock, but green, yellow, dichroic, in thin sections, and peculiarly impure from the inclosure of quartz grains. Biotite, magnetite, and apatite are constant, augite and fluor spar are frequent, constituents.

But what gives to this rock a very marked microscopic individuality is the uniform presence in it of well-crystallized square prisms of zircon. Of the many sections that have been cut, not one has been found free from these pretty crystals. They are large enough to be examined optically under the microscope, and are easily recognized by their tetragonal crystallization and their high index of refraction. Their uniaxial and positive character can be easily determined in convergent light. Out of twenty-five grams of the rock from Mount Willard, I separated several hundred of these

* For distribution of this granite see Hitchcock's *Geol. New Hampshire*, vol. ii, p. 143.

† Sections parallel to the base hardly show these interlaminations owing to the approach in the elasticity planes of the two species. Sections parallel to the clinopinacoid possess an elasticity plane making an angle of 6° with the basal cleavage, and in the interlaminations an elasticity plane makes an angle of 17° in the same direction with the basal cleavage.

crystals by means of hydrofluoric acid. They are white, clear, and glassy, but are sometimes tinged with yellow. They are often 1-10 mm. in diameter and 4-10 mm. long. Their surfaces are bright, but cavities often penetrate far into their interiors. They are doubly terminated, and, in addition to the planes of the prism and pyramid of the first order, they frequently have the planes of a ditetragonal pyramid which is probably the form 3-3. They contain many inclusions. Some of these are the inverted forms of zircon crystals, some are zircons with different terminal faces, and some are empty cavities with very irregular forms.

In the middle of the arm of Albany granite which extends across the summit of Mount Willard, the rock is of this normal character, but both to the right and the left differences are evident. These differences are of the same character upon both sides, but they are very much more marked upon the side of the schist. At a distance of 100 feet from the contact, the crystals that form the granite have become smaller with the exception of the large feldspar crystals, which are in consequence more conspicuous. At a distance of sixty feet a tendency in the quartz to assume crystalline forms is noticed, and the rock begins to appear porphyritic. At fifteen feet from the contact with the schists, the quartz is found in well-defined dihexagonal pyramids, as large as peas, and these with the Carlsbad twins of orthoclase are imbedded in a ground mass no longer resolvable by the unaided eye or lens. Upon the contact the ground-mass is nearly black in color, flinty in texture, and apparently homogeneous. The Albany granite has become a quartz porphyry.*

* The Bodegang previously referred to is filled with quartz porphyry which, however, has a coarser ground-mass in the center.

In the Vosges the granites which have altered the slates are upon their side usually unaffected. At one spot, however, in the Weihermattenthal the granite becomes porphyritic upon the contact. Rosenbusch, *Die Steiger Schiefer und ihre Contactzone an den Granititen von Barr-andlau und Hohwald*, p. 156.

In the Pyrenees near Case de Brousette a contact occurs between clay slate and a porphyry which farther south gradually changes into granite. Zirkel, *Zeitschr. d. d. Geol. Ges.*, 1867, p. 106.

The accompanying microscopic changes are as striking. Approaching the contact there is a continual diminution in the amount of the hornblende and the size of its crystals. There is a corresponding increase in the amount of the biotite, which finally entirely replaces the hornblende. These biotite crystals are at first quite large, but they diminish rapidly in size near the contact, and upon the contact are reduced to a dust. The ground-mass which makes its appearance between the quartz and orthoclase crystals, grows finer, but upon the contact, though of extreme fineness, it is still entirely crystalline. In this ground-mass all the minerals of the granite found in specimens distant from the contact are recognizable, but near the contact no individual crystals can be determined.

In this series of changes all the minerals have taken part with two exceptions. The Carlsbad orthoclase twin crystals and the zircon crystals have the same shape and size in all parts of the rock. That is, with these exceptions the condition or existence of the mineral components depends upon position with reference to the contact.

These modifications, which are repeated in a less conspicuous manner upon approaching the contact with the granite upon the opposite side of the mass, are such as might be induced in a molten eruptive mass, which, like modern lavas, contained some crystals already formed at the time of eruption by the effect of contact with cold walls, the hydrous nature of one and the anhydrous nature of the other being factors modifying the extent of the effect.

Any chemical changes that may be connected with these modifications are represented in the following table of analyses.

Of the differences here shown some fall within the evident errors of the analyses; and so many of the others can be referred to differences introduced in sampling such coarse-grained compounds, that I do not think that any changes can be definitely referred to the effect of contact, unless it be the accession of iron, and the slight hydration. If we assume that no chemical change has taken place, and that

	Normal Albany granite.	Granite porphyry 3 ft. from contact.	Granite porphyry 2 in. from contact.
SiO ₂	72.26	73.09	71.07
Al ₂ O ₃	13.59	12.76	12.34
Fe ₂ O ₃	1.16	1.07	2.25
FeO	2.18	4.28	4.92
MnO	tr.	0.08	tr.
CaO	1.13	0.30	0.55
MgO	0.06	0.09	0.19
K ₂ O	5.58	5.10	5.53
Na ₂ O	3.85	3.16	2.84
TiO ₂	0.45	0.40	0.27
H ₂ O	0.47	0.73	0.72
	100.73	101.06	100.68
Sp. gr.	2.65	2.66	2.68

the first analysis represents the whole, a calculation shows that it may contain:—

	Quartz.	Orthoclase.	Albite.	Anorthite.	Hornblende.	Biotite.	Magnetite.	Titanic iron.
	25.99	32.95	32.61	1.35	4.83	. . .	1.68	0.85
Or,	26.79	30.76	31.01	5.65	. . .	5.44	. . .	0.85

The biotite has the composition $(K, Na)_2(Fe, Mg)_4AlSi_4O_{16}$ (= one molecule K and one M of Tschermak) and the hornblende will be $11(RSiO_3) + Al_2O_3$. This calculation cannot claim to be accurate since there are no data for dividing the lime between the anorthite (which is supposed to be combined with some of the albite to make a triclinic feldspar) and the hornblende. It is introduced to show that the results of the chemical investigation do not at all contradict the microscopic results, since a recrystallization and a rearrangement in the proportions between the feldspars furnishes all the material necessary to convert the hornblende into biotite.

The schists that occupy the area indicated upon the map form portions of Mts. Tom, Field, Willey, and Willard, elevations in the vicinity of the White Mountain Notch. Their age is unknown. Their reference to the Silurian on account of a supposed fossiliferous character being based

upon an error, it is only certain that they are older than both the Albany and the Conway granites, both of which intersect them. In composition they are not at all constant, but the prevailing variety is a dark compact argillitic mica schist with andalusite crystals scattered through parts of it. Upon the summit of Mt. Willard they appear to be very uniform over a large area, and for this reason the specimens for chemical study were taken from this spot.

The schists at the summit have a strike very nearly north and south, and they dip 60° to the west.* The line of contact with the granite runs in an irregular northwest direction. At a distance of one hundred feet from this contact, with the exception of the rather rare andalusite crystals, no minerals are visible in this schist to the unaided eye, unless the glistening surface be considered as an indication of mica. Under the microscope it is seen to consist of quartz, muscovite (probably the variety containing combined water) and chlorite. Titanic iron partially decomposed into leucoxene, some magnetic iron which can be drawn from the powder with a magnet, and particles resembling coal or graphite, constitute opaque black ingredients. A little biotite and a very few crystals of tourmaline, recognized by form and the direction of strong absorption, are accessory constituents. No marked change is visible in the rock at a distance of fifty feet from the contact, but nearer than this point the effect of the contact becomes very soon evident. As the specimens described and analyzed were all, with the exception of the normal schist at one hundred feet, taken from the same stratum, I think that all the differences noted may be with certainty regarded as due to the effect of contact.

Twenty-five feet from the contact the schists are much changed in microscopic structure. They are more definitely and coarsely crystalline; biotite becomes a more prominent constituent, and tourmaline crystals, blue within and brown without, have become a prominent constituent.

* Strike of slate 12° - 22° W., strike of contact N. 77° W. Hitchcock's *Geology of New Hampshire*, vol. ii, p. 177.

Between this point and the contact the changes apparent to the eye are marked and rapid. At fifteen feet the rocks are still schistose, but they are hard, much fractured, and full of shining dots that indicate a new crystallization. At this point the rock is a mica schist. Under the microscope, a decrease in the amount of chlorite and an increase of biotite are noted, also the presence of many tourmalines and of large, clear quartz grains with fluidal inclosures. The titanite is entirely altered into a dull white opaque substance.* Between this point and the contact the schist loses entirely its schistose structure, and is converted into a black hornstone, which breaks into small angular fragments. The little bright crystalline grains of quartz increase in quantity, and the tourmalines become much more numerous. From the schists ten feet from the contact a qualitative reaction for boric acid can be obtained. The rock, which thus far has been growing coarser in texture, from this point grows gradually finer, and is converted near the contact into flinty, compact hornstone, thin sections of which are resolved by the microscope into an aggregate of quartz, biotite, tourmaline, and iron oxide.

But between this hornstone and the granite another well-defined zone exists. This is a dark gray mass which is filled with reticulated black veins. Scarcely noticeable on the top of the mountain, this zone becomes wide and prominent below. The veins which fill this mass divide and subdivide, giving to the whole a fused, slaggy appearance. Under the microscope, however, this mass is resolved into a nearly pure mixture of tourmaline and quartz. While in the hornstone zone last described, the tourmalines are in extremely minute formless grains, here they are in more or less well-defined crystals, and possess a concentrically-banded structure. White, blue, light brown and dark brown layers follow one

* I cannot regard the conclusion of Prof. v. Lasaulx that this substance is titanite of lime, titanomorphite, as certainly correct in all cases, for in rocks like this that are nearly free from lime the same decomposition takes place. In this case there is not enough lime in the whole rock to make titanomorphite with the titanite acid.

another in the order named. These crystals are bounded by the planes $-\frac{1}{2}R. - \frac{iR.}{2}i2$. This mass I characterize as the zone of the tourmaline veinstone to distinguish it from the last, or the zone of the tourmaline hornstone. There is reason for this in the circumstance that the impregnating material has wholly altered the character of the schist.

The chemical changes that have taken place, both in ultimate composition and mineral constituents, are indicated in the following table of analyses: —

	Schist 100 ft. from contact.	Schist 50 ft. from contact.	Schist 15 ft. from contact.	Tourmaline Hornstone 1 ft from contact.	Tourmaline Veinstone on contact.
SiO ₂	61.57	63.35	66.30	67.88	66.41
Al ₂ O ₃	20.55	19.69	16.35	14.67	16.84
Fe ₂ O ₃	2.02	0.72	0.95	2.37	1.97
FeO	4.28	5.48	5.77	3.95	5.50
MnO	0.10	0.16	tr.	0.11	0.12
CaO	0.24	tr.	0.24	0.30	0.37
MgO	1.27	1.77	1.63	1.29	1.71
K ₂ O	4.71	3.47	3.40	4.08	0.56
Na ₂ O	0.63	1.12	1.11	3.64	1.76
TiO ₂	1.10	1.00	1.28	0.93	1.02
B ₂ O ₃	...	...	tr.	0.97	2.96
Fl	...	...	...	tr.	0.25
H ₂ O	4.09	3.73	3.02	1.01	1.31
	<u>100.61</u>	<u>100.49</u>	<u>100.05</u>	<u>101.20</u>	<u>100.78</u>
Sp. gr.	2.85	2.84	2.82	2.74	2.73
Quartz	36.87	39.17	45.15	50.82	50.03
Muscovite . . .	49.30	44.53	43.89	29.67	...
Biotite	...	...			
Chlorite	8.62	13.70	6.65	...	...
Titanic iron . .	2.09	1.90	2.43	1.77	1.94
Magnetite . . .	2.93	1.04	1.38	3.44	2.86
Tourmaline . . .	...	...	...	14.92	45.95
Excess of H ₂ O .	0.80	0.15	0.55	0.58	...
	<u>100.61</u>	<u>100.49</u>	<u>100.05</u>	<u>101.20</u>	<u>100.78</u>

In these analyses a systematic and progressive series of changes indicates that there has been an addition to the schists by reason of contact with the granite. The dehydration and the accession of boric and silicic acids are positive features, and the addition of alkali directly upon the contact, in consideration of the circumstances that the second, third, and fourth samples were taken from the same stratum, may be regarded as certain also. The series of analyses given by Professor Rosenbusch in his work upon the contact phenomena in the Vosges* prove, in his opinion, that, whatever may have been the physical changes, nothing (except in one case a little boric acid) has been added to the schists, and the analytical results obtained by others from contact schists lead to the same result. The kind of changes indicated by my analyses, if of less degree, are of the same kind as those that have been observed in the contact of granites with limestones, as for example in the Harz, where the limestones about the Ramberg† have their CO_2 replaced by SiO_2 , forming a broad zone of lime silicates about the contact; and on the contact of limestone with Monzonit‡ at Predazzo, where a similar lime-silicate hornstone zone is found to be rich in alkali directly upon the contact.

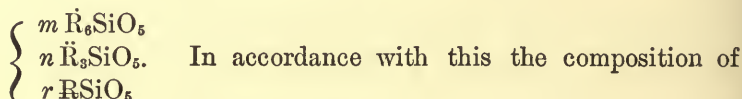
The effect of the contact becomes much more striking when the percentages of the constituent minerals are calculated from the analyses. This was done in the first two analyses, as follows. The titanium dioxide was first reckoned into titanite, and the iron sesquioxide calculated into magnetite, since the magnet attracts black particles from the powder. The remaining iron protoxide, with the manganese oxide, and the magnesia were then calculated into a chlorite of the formula of ripidolite ($\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{14} + 4\text{H}_2\text{O}$). Then if the remainder of the alumina is calculated into muscovite $(\text{K}, \text{H})_2\text{Al}_2\text{Si}_2\text{O}_8$, nothing at all is left save the small percentages of water indicated in the table, which are

* Die Steiger Schiefer und ihre Contactzone. Strassburg, 1877, p. 257.

† Lossen, Zeitschr. d. d. Geol. Gesellschaft, xxiv, p. 777.

‡ J. Lemberg, Zeitschr. d. d. Geol. Gesellschaft, xxiv, p. 234

not much more than what may be supposed to be hygroscopic, or included. In the third analysis, the protoxides, before calculated as belonging wholly to chlorite, have been divided equally between chlorite and biotite in accordance with the microscopic indication. The tourmaline hornstone is a nearly pure mixture of tourmaline and quartz, as shown by the microscope, hence in the last analysis, after calculating the amount of titanitic iron and magnetite, the remaining bases were calculated as forming a tourmaline of the formula.



the tourmaline is as follows:

SiO ₂	Al ₂ O ₃	FeO	MnO	CaO	MgO	K ₂ O	Na ₂ O	H ₂ O	B ₂ O ₃	Fl
35.65	36.66	8.03	0.26	0.79	3.72	1.22	3.83	2.85	6.45	0.54 = 100

The fourth analysis can now be calculated like the third, after deducting the percentage of tourmaline calculated from the boron trioxide. If biotite is considered as a combination of the muscovite molecule $(\text{K}, \text{H})_2 \text{AlSi}_2\text{O}_8$ with the molecule $\text{Mg}_2\text{Si}_2\text{O}_8$ (according to Tschermak) we have the data only for obtaining the sum of the muscovite and biotite, but not the amount of each. If the data of these calculations are not absolutely correct, the results agree well with the microscopic observations, and the table I think indicates clearly both the chemical and mineralogical changes, and makes it plain that they are progressive in approaching the granite.

Just between the schist and granite, upon the summit of the mountain, a very insignificant zone exists which consists of granite in which numerous fragments of a variety of rocks are included. This zone, scarcely noticeable upon the summit, becomes larger and better defined as one descends the cliff, and I shall show what a weighty part this little zone, here but a foot or two wide, plays elsewhere. This zone I call the *mixed zone*. At a short distance below the summit it becomes a very sharply defined band three feet wide, and

consists of fragments of various kinds of schist, and angular fragments of a foreign variety of quartz porphyry, and all are cemented together with the granitic material. The feldspar crystals in this granite are all broken to fragments,* and the whole mass is impregnated with tourmaline, but the constituent minerals are all easily recognized. The different zones that I have described are here all sharply defined. To recapitulate, these zones are as follows:—

1. Zone of the argillitic mica schist (chloritic).
2. Zone of the mica schist (biotitic).
3. Zone of the tourmaline hornstone.
4. Zone of the tourmaline veinstone.
5. Zone of the mixed schists and granite.
6. Zone of the granite porphyry (biotitic).
7. Zone of the granite (hornblende).

It will thus be seen that the succession of zones is different from those that have been described about other granitic masses, but that the effects observed are of the same nature and referable to the same causes.†

Following the line of contact down the cliff, the phenomena of the contact ever becomes more extensive and remarkable. At a point just above the spot figured, a long arm of the porphyritic granite, from two to three feet wide and eighty feet long, extends into the schist at nearly a right angle to its stratification. The impregnation of the schists with tourmaline has been much more effectual below than upon the summit. Two hundred feet below the summit the schists distant one hundred feet from the contact contain as many tourmalines as at fifteen feet from the contact upon the top. The mixed zone steadily increases in width as it descends, and at the base of the huge cliff it is more than twenty feet wide.

* The crystals of orthoclase found in the small branches of granitic masses where they would be subjected to friction have been often found broken. In the Fichtelgebirge and Elba for example. Credner *Geologie*, p. 285.

† The zones in the Vosges as described by Rosenbusch are: 1. Clay slate; 2. Knotty clay slate; 3. Knotty mica schist; 4. Hornstone, usually andalusite hornstone. The knotty character is here entirely absent.

These are the main features of this remarkable contact. I think they show that the Albany granite is an eruptive mass younger than the Conway granite, and younger than the andalusite schists, and that the main portion of its mass had not crystallized at the time of eruption. The inclusion of such varied products in the mixed zone indicates that it moved no inconsiderable distance through fissures in very diverse rocks. The kind of impregnation indicates that it was accomplished by vapors and solutions that emanated from the fissures filled by the granite; but the impregnation of schists imbedded in the granite, and the impregnation of the schists attendant with a dehydration of the same, indicates the action of very hot vapors which accompanied the eruption; not the action of vapors subsequently emanating through the cleft.*

The line of division forming the contact is microscopically fine. Over this line the minerals of schist or granite do not pass except in the form of inclusions. There is therefore no relationship between the schist and the granite.

These results are of importance in White Mountain geology since the effects are often repeated. All about this area, and other areas of Albany granite as far as observed, the effects of the contact are found upon the edges of the granite. At Bemis Brook the same apparent effects are seen on the side of the granite, but the schists, which are hard siliceous mica schists, have not been affected. The porphyry which at this spot adjoins the schist has the granophyre † structure. This structure may therefore be induced as a contact phenomenon.

* In the Vosges andalusite is the mineral characteristic of the contact, and the question having been raised whether andalusite ever occurs save as a contact mineral, this has been considered. The apparently systemless method of distribution of andalusite crystals over the whole area gives no basis for referring these macled crystals to the effect of contact.

The cavities in the quartz of the granite contain most variable amounts of fluid. Some are full and some are empty. The calculation of temperatures and pressures upon measured size of bubble and cavity can be of little value when, as is here plain, other unknown quantities beside those commonly considered are factors.

† Used in the sense of Rosenbusch. That is, the quartz and feldspar of the ground-mass are arranged with reference to one another, as in graphic granite.

Ascending Mt. Kearsarge by the bridle path from the Intervale station, the base of the mountain is seen to be composed of Conway granite.* At a height of five hundred feet one finds the peculiar gray porphyry with Carlsbad twins of orthoclase and dihexagonal pyramids of quartz, as on Mt. Willard, and which we recognize as the zone of the quartz porphyry, which gradually changes and finally becomes typical Albany granite. Here again we see that the Conway granite was a cool body influencing the crystallization of a later eruption. After climbing for a short while over the Albany granite, the zone of porphyry again appears; then follows in proper sequence the mixed zone, but this zone which upon Mt. Willard attains to a width of twenty feet here forms the whole grand mass of Kearsarge, Bartlett and Moat Mountains. These mountains from base to summit consist of angular pieces of schists intermingled with and cemented by granite porphyry. The schists have been modified by the contact, but to a less degree, since there has been here no impregnation with tourmaline. The mixed mass adjacent to the schists consists of a very large amount of broken schist, cemented by a small amount of the granite, which has been accordingly much modified by the effect of the schist, and has a ground-mass very fine in texture, and homogeneous and flinty in appearance. Above, where there is a smaller proportion of schist in the porphyry, this ground-mass becomes more coarsely crystalline, and approaches granite in texture. The microscopic peculiarities, however, remain constant and the large iron crystals never fail.

I have endeavored to show that the contact phenomena connected with the Albany granite are very beautifully developed upon a small scale, affording thus exceptional facilities for study and observation; but that on the other hand they reach an unequalled grandeur of proportion. The evidence previously offered by others has not been decisive in determining the eruptive or metamorphic origin of this rock, and I point to the fact that many other important granite masses

* See also Atlas to the Report on New Hampshire Geology, Hitchcock.

have been referred to the one or the other of these groups upon the same insufficient evidences of structure and internal stratification. From observations incidental to this work I am, however, quite certain that the study of the contact phenomena of the other great granitic masses in New Hampshire would develop as many interesting lithological facts, and furnish the proper evidence for a determination of their origin.

ON THE PETROGRAPHY OF SQUARE BUTTE IN THE HIGHWOOD MOUNTAINS OF MONTANA.

By L. V. PIRSSON.*

INTRODUCTORY NOTE. Square Butte is a rudely circular mass of igneous rock resting on the point of the tableland at the juncture of the Arrow River and Shonkin Sag valleys on the east side of the Highwood Mountains of Montana. This platform consists of shales and sandstones of the Cretaceous. The butte with its flat top forms the most dominant landmark in this part of the region, and is visible for many miles across the wide stretches of level prairie lands which surround it. At the base its diameter is about two miles, at the top about one, and its thickness is about fifteen hundred feet.

The lower part of the mass consists of the dark rock described as shonkinite in the following article, and this has been carved by erosion into a series of towers, crags, buttresses, etc., with small wooded glens between, which completely surround the lower base of the butte. Their number and complexity is so great that they form labyrinthine mazes all along the lower slopes. In one place they are cut by a band of white rock which, except for a certain peculiarity mentioned later, appears much like a narrow dike. Ascending through this maze of rock monoliths at a certain height the dark basic shonkinite is replaced by a white sodalite syenite, whose light color is in striking contrast to the dark rock below. There is, however, no contact between the two masses, one kind of rock passes within a short distance into the other by gradual transition without change of grain or other contact phenomena. The mass, as a whole, has a marked platy parting parallel to the general slope, and this passes through white syenite and dark shonkinite alike and also through the white band mentioned above without regard to their differences of composition.

* From the "Highwood Mountains of Montana," by Walter H. Weed and Louis V. Pirsson. Bull. of the Geol. Soc. of America, vol. 6. pp. 389-422, 1895.

The study of the mass and its relation to the surrounding sediments forces the conclusion that it is a denuded laccolith, and that the differences of its rock types have been produced by differentiation after the mass was intruded in the molten condition.

PETROGRAPHY OF SQUARE BUTTE.

Characteristics and Minerals of the dark Rock, Megascopic and Microscopic.—The dark rock seen at a distance appears of a grayish black or dark stone color, like many basic diorites. In the hand specimen, however, it is found to be so coarse-grained that the distinction between the dark colored ferromagnesian components and the light colored feldspathic ones becomes strongly accentuated, the contrast giving the rock a mottled appearance.

Thus, by inspection of the specimen, one readily distinguishes the chief components. They are augite in well formed, often rather slender, idiomorphic crystals, of a greenish-black color, attaining at times a length of one centimeter, but not averaging perhaps more than a quarter of that length, and biotite, of a bronzy-brown color, whose occasional cleavage surfaces attain a breadth of from one to two centimeters, but whose outlines are not clear and idiomorphic, but irregular, dying away among the other components in shapeless patches. These biotites are, moreover, extremely poikilitic, inclosing the other components. With the lens these broad cleavages are seen to be made up of great numbers of smaller biotite individuals in parallel growths, but including the other minerals. They are thus, as one might say, spongy, skeleton crystals on a large scale.

Filling the interspaces between these dark minerals is a white feldspathic material, from which one obtains occasionally the reflection of a good feldspar cleavage. With the lens one detects greenish grains of olivine in addition.

An inspection of the rock shows at once that its predominant character is the great abundance of the augite, which must form at least one-half of the mass by volume and a greater

proportion by weight. With this large amount of augite, it is clear that if it were a dense fine-grained rock, instead of being so coarse-grained as it actually is, a pronounced basaltic appearance would characterize it.

In texture the rock is rather friable and crumbly, and blows of the hammer will frequently cause a specimen to fall into a coarse gravel. This is not due necessarily to alteration, but to the great number of pyroxene prisms and their idiomorphic character, there being little adhesion between their polished faces and the white feldspar material which fills their interspaces. A single heavy blow will often loosen these prisms so that the rock will crumble under the fingers.

In thin sections under the microscope the following minerals are found to be present: Apatite, iron ore, olivine, biotite, augite, albite, anorthoclase, orthoclase, sodalite, nephelite(?), cancrinite(?) and zeolites.

Apatite. — This is the oldest mineral, appearing in idiomorphic outlines even in or abutting into the iron ore. It is in short, stout prisms which often attain a length of 0.5 millimeter. Though commonly colorless, it is at times filled with excessively fine, dusty particles, and then becomes pleochroic: ϵ = pale steel-blue; ω = pale leather-brown. This dusty pigment is very apt to be confined to an inner core, which is surrounded by a clear colorless zone. Sometimes the apatites are of a pale red-violet-brown and nonpleochroic. The crystals are bounded by the unit prism and several pyramids, but they were too small to determine the planes on materials separated by the heavy liquids. The basal parting is common. Cases of twinning like that mentioned by Washington* were not observed. As shown by the analysis, the mineral is present in considerable amount.

Olivine. — This mineral presents the usual type, but is at times of a very pale yellowish color in the section and then shows a faint but clearly perceptible pleochroism in tones of yellow and white. It is generally quite fresh, but sometimes has borders and patches of alteration into a reddish ferruginous material.

* Jour. Geol. Chicago, vol. viii, 1895, p. 5.

Biotite. — The large cleavage surfaces of this mineral, made up of composite individuals, have been described above. It is strongly pleochroic, the colors varying between a very pale brownish orange and a deep umber brown. Cleavage plates appear uniaxial, but in the section, where very thin edges may be found, there is enough of an opening to the arms of the cross in convergent light to establish it as meroxene, the usual variety. The twinning and inclined extinction sometimes seen in the biotites of nephelinite and theralite rocks were not observed.

Besides this brown variety of biotite, there is present also in much smaller amount a pure deep green kind, which, from its method of occurrence, we infer has been formed from the brown one. All gradations are found between them, but in such cases the brown forms an inner core which changes to green on the outer edges. This green kind is particularly to be seen around the olivines, and especially where they come in contact with orthoclase. The appearance of these colorless olivines surrounded by this deep green mantle is very striking. This variety shows very little change of pleochroism or absorption; it is uniaxial, and its double refraction is equally strong with that of the brown. It is quite irregular in outline.

The intermediate position that biotite, in respect to its chemical nature, holds between olivine and feldspar has been noted by Iddings* and is shown in the analysis of its formula. Thus if we consider typical biotite as $(HK)_2(MgFe)_2Al_2Si_8O_{12}$, this separates into $(MgFe)_2SiO_4 + (HK)_2O + Al_2O_3 + 2 SiO_2$, thus furnishing olivine and the oxide molecules necessary for orthoclase. It is possible that this intimate relation may condition the appearance of secondary biotite where olivine and orthoclase are contiguous.

Pyroxene. — Of all the ferro-magnesian minerals this is by far the most important, determining with the orthoclase the essential character of the rock. Owing to the ease with which it may be detached from the matrix, excellent speci-

* Origin Igneous Rocks: Bull. Phil. Soc. Washington, vol. xii, 1892, pp. 165, 166.

mens may be obtained for crystallographic study. In general they present the common form of augite bounded by the planes $a(100)$, $b(010)$, $m(110)$ and $s(\bar{1}11)$, and somewhat tabular on $a(100)$. The form $o(221)$ has also been observed. Twinning on $a(100)$ occurs, and a crystal of this type having the form $o(\bar{2}21)$ in addition was measured on the reflecting goniometer with the following results:—

	Theory.	Measured.			
$a \wedge m (100 \wedge 110)$	$46^\circ 25'$	$46^\circ 27'$	$46^\circ 23'$	$46^\circ 42'$	$46^\circ 51'$
$s \wedge s (11\bar{1} \wedge 111)$	$59^\circ 11'$	$59^\circ 8'$			
$m \wedge o (110 \wedge 221)$	$35^\circ 29'$	$35^\circ 40'$			
$s \wedge \bar{s} (11\bar{1} \wedge 111 \text{ twin})$	$26^\circ 52'$	$26^\circ 24'$	$26^\circ 35'$		

The reflections of the signal were only moderately good, and the measured angles are therefore of value only in determining the faces.

As this variety of augite is very common and persistent, not alone at Square Butte but generally throughout the Highwood rocks, at times, however, passing into varieties which have a narrow mantle of material rich in the ægirite molecule, as, for example, ægirite-augite, it has been deemed important to investigate it chemically, especially since the Square Butte rock presents such excellent material. The analysis yielded the following results:—

ANALYSIS OF PYROXENE.

		Oxygen ratios.
SiO ₂	49.42	0.8236
TiO ₂	0.55	0.0067
Al ₂ O ₃	4.28	0.0415
Fe ₂ O ₃	2.86	0.0178
FeO	5.56	0.0772
MnO	0.10	0.0014
MgO	13.58	0.3395
CaO	22.35	0.3995
		(1.00)
Na ₂ O	1.04	0.0167
K ₂ O	0.38	0.0040
H ₂ O (at 110°)	0.09	
Total . . .	100.21	

In the foregoing analysis the rock was crushed, sifted, and the resulting powder washed and then separated by the use of Retgers' * silver-thallium-nitrate fluid in the apparatus devised by Professor Penfield,† and by this means, aided by the magnet, material of exceptional purity was obtained.

The comparison of the ratios in the analysis shows that CaO to (FeMg)O is as 1 to 1, and that the diopside molecule is thus chiefly present. The presence of the alumina suggests that Tschermak's molecule $\ddot{R}Al_2SiO_6$ must also be present. If we subtract from the sum of the RO molecules enough to make the number of the R_2O equal to that of the R_2O_3 and take out the same number of SiO_2 molecules, the following table shows the composition of the augite:—

$$\begin{array}{l} R_2O = 0.0207 \\ RO = 0.0386 \end{array} \left. \vphantom{\begin{array}{l} R_2O \\ RO \end{array}} \right\} 0.0593 : R_2O_3 = 0.0593 : SiO_2 = 0.0593 :: 1 : 1 : 1. \\ RO = 0.7790 : SiO_2 = 0.7710 :: 1 : 1.01.$$

The very striking agreement of these ratios with the theory must certainly be held to add another very strong proof to the correctness of Tschermak's assumed molecule. The augite then has almost exactly the following composition: $13Ca(MgFe)Si_2O_6 + 2(Na_2\ddot{R}(AlFe)_2SiO_6$.

Since the qualitative analysis of the feldspars has shown the absence of lime, if we deduct enough from the amount found by the mass analysis of the rock to turn the phosphoric anhydride into apatite, a comparison of the remaining amount, 11 per cent, with the 22 per cent of lime demanded by the pyroxene, shows this mineral forms one-half of the rock by weight, a fact which agrees with the appearance of the hand specimen and the study of thin-sections.

* Jahrbuch für Min. 1893, vol. i, p. 90. This most happy discovery of Professor W. Retgers has placed all working mineralogists and petrographers deeply in his debt.

† We desire to express our thanks to Professor S. L. Penfield for kindly aid in making the separation in apparatus recently devised by him for the special use of the Retgers' fluid, and by means of which the operation may be carried on with nearly the same ease and with all the certainty of the usual heavy liquids.

Orthoclase. — The predominant feldspar is orthoclase. This is shown by the study of thin-sections, by the separation of the feldspathic constituents by heavy liquids, and may also be inferred from the chemical analysis of the rock, where potash is seen to greatly predominate over soda. The mineral is quite fresh and wholly allotriomorphic, its shape being determined by the angular interspaces between the pyroxenes in which it is found. Sometimes it assumes rude lath-shaped forms.

It is apt to be filled with fine interpositions whose exact nature cannot be told. They commonly possess the form of their host and their longer axis coincides with that of the crystal, and, so far as can be determined, they are arranged in planes parallel to prism faces. They do not contain bubbles, the reflection band surrounding them is narrow and they do not act on polarized light. From these facts we believe them to be of glass.

Sometimes the orthoclase is colored a pale brownish tone by a fine dusty pigment. It shows in some places a slight tendency to kaolinization and in some others is discolored by the alteration of its interpositions, but usually it is quite fresh. The angle of the optic axes is variable, generally small and sometimes nearly zero.

It sometimes shows intergrown patches of a feldspar which has a higher index of double refraction and is believed to be anorthoclase. In a few cases a tendency for orthoclase laths to group themselves in radial spherulitic forms starting from a common centre was observed; since the laths are broad and coarse it does not present a striking feature. Again, in other places the patches of orthoclase filling adjoining areas between augites and olivines have the same optical orientation over some distance, thus presenting a rude poikilitic effect.

Plagioclase. — A triclinic striated feldspar is also present, but in no considerable amount. When the rock powder is placed in the mercuric-iodide solution, and the ferro-magnesian minerals, the magnetite and apatite have fallen out, no

feldspathic materials are deposited until a specific gravity of 2.60–2.61 is reached. At this point a very small precipitate is obtained of a feldspar insoluble in HCl. Subjected to qualitative analysis it is found to be free from lime and gives abundant reaction for soda. It is therefore albite, which agrees with the optical character of the mineral in thin-sections, the extinction on either side of the albite twinning plane reaching a maximum of about fifteen degrees. The study of this striated feldspar has shown that certain crystals possess remarkable properties. Thus the twinning lamellæ, which are very narrow, can be seen in many cases very distinctly in ordinary light without using the analyzer, some of them possessing a higher refraction than others. Between crossed nicols it is seen that crystals possessing this peculiarity have no position of equal illumination, but the lamellæ can be seen in all positions. It must be, therefore, that these lamellæ possess a different chemical composition from those adjoining them, and since lime is excluded they must represent intergrowths of albite and anorthoclase of varying composition, joined after this singular manner.

Recently Federoff* has called attention to similar intergrowths of twin lamellæ of different composition in the lime-soda feldspars, and the same phenomenon had been studied and noted previously by Michel-Levy.†

Nepheline. — The presence of this mineral is only indicated by the fact that the powders falling between the specific gravities of 2.55 and 2.60 dissolve slightly in HCl, giving a small amount of gelatinous silica, with reactions for Na and none for Cl, H_2O or CO_2 . It must be present in the rock only as a rare accessory mineral, and the recognition in the thin-sections of an occasional patch is rendered difficult by the practically uniaxial character of some of the orthoclase.

Cancrinite. — This is indicated by the fact that the rock powder obtained at a specific gravity of 2.47 dissolved in HCl with gelatinization, and in dissolving slowly and con-

* Zeit. für Kryst. vol. 24, Hefte 1 and 2, 1894, p. 130.

† Minéraux des Roches: Paris, 1888, p. 84.

tinuously gave off CO_2 , while carbonates, which would have been thrown down at a higher specific gravity, are absent in the rock, as seen in thin-sections. It can be present only in very small amount, and the certainty of recognizing an occasional piece in the section is diminished by the common occurrence of natrolite. The two minerals are alike in their appearance in fibres with parallel extinction. The cancrinite has, it is true, a higher double refraction, but sections may be as low as natrolite, and only by establishing the uniaxial character can the cancrinite be definitely determined. This we have not been able to do, and its presence is therefore only inferential.

Sodalite. — This also occurs as an accessory component. The rock powder separated below a specific gravity of 2.40 consists partly of this mineral, together with some zeolites. It dissolves readily in HCl and HNO_3 , the solution in the latter yielding a precipitate with AgNO_3 and none with BaCl_2 , thus showing the presence of sodalite and absence of hauyn or nosean. In thin-section it is very clear and limpid, but contains little interpositions somewhat like the feldspars. The actual amount of sodalite in the rock is very small, and this is shown also by the small amount of chlorine obtained in the analysis, part of which belongs to the apatite present.

Natrolite. — The presence of zeolites is indicated by the water obtained in the analysis. Some analcite may occur, but the chief zeolite is natrolite, which is present in considerable amount. It is recognized by its parallel extinction and positive character, by the small angle of the optic axes, and by the strength of its double refraction, which compared with the feldspars, rises to 0.010–0.012. It occurs in characteristic bundles of fibers, and is in part secondary after sodalite and in part after albite and anorthoclase. The fibers are plainly seen eating their way into the feldspar, and in a given crystal they do this according to a definite oriented direction, as the different patches in the crystal always have the same orientation.

Chemical Composition. — The chemical composition of the

rock is shown in the following analysis. In it the minute trace of CO_2 due to a little possible cancrinite is not determined, nor is the amount of rarer elements which could not influence its results. The very large amount of P_2O_5 is noticeable, and proves what the microscope reveals, the large amount of apatite present. The amount was fixed by two closely agreeing determinations.

ANALYSIS OF SHONKINITE.*

SiO_2	46.73
TiO_2	0.78
Al_2O_3	10.05
Fe_2O_3	3.53
FeO	8.20
MnO	0.28
MgO	9.68
CaO	13.22
Na_2O	1.81
K_2O	3.76
H_2O	1.24
P_2O_5	1.51
Cl	0.18
	100.97
$\text{O} = \text{Cl}$	0.04
Total	
	100.93

To be noted here is the low silica and very high magnesia, iron, and lime. It is evident that although the feldspar raises the silica percentage it is not in sufficient amount to counteract the olivine, iron ore, biotite, apatite and other minerals which tend to lower it. The water comes in part from zeolites.

Structure and Classification. — The minerals in the order of their crystallization are, first, apatite, then iron ore, olivine, biotite, and augite. The period of the last two

* Since this analysis was published a recalculation of the analytical data shows an error in calculating the MgO which should be 9.25 and the total 100.50.

overlaps. Then followed the feldspathic components, whose succession is quite doubtful as regarding one another, except that on the whole the albite-anorthoclase group appears to be among the earliest.

These minerals lie unoriented, forming a holocrystalline, rather coarse granular hypidiomorphic structure. It resembles in many respects the coarser grained theralites of the Crazy Mountains; in others certain coarse-grained dolerites.

From what has been given in the foregoing description it is evident that in this dark rock of Square Butte we have a granular, plutonic rock, composed essentially of *augite* and orthoclase, with smaller amounts of olivine and iron ore and with accessory apatite, sodalite, nepheline, et cetera. In its chemical composition it stands very close to certain vogesites and minettes — basic rocks of the syenitic group. It differs from them essentially, first, in its mineral composition and, second, in its structure. For a rock of its character there seems to be no position in any of our present schemes of classification. It would be manifestly improper to term such a rock an augite-syenite, as its chemical composition removes it very far from syenites. It bears, indeed, such a relation to augite-syenite as vogesite does to hornblende-syenite; that minette or, perhaps, better, the Durbachite of Sauer* does to mica-syenite.

It stands generally related indeed to rocks of the basic class — low in SiO_2 , high in MgO , CaO , and FeO , and thereby related to rocks of the lamprophyre family. Moreover, this type is found in the Highwoods not only in the outer mantle of Square Butte, although constituting there an immense mass, but at many other points forming great intrusive stocks. As briefly noted by Lindgren,† the variability of the augite and orthoclase in the Highwood rocks is very great. As in the gabbro family we have every range from anorthosite at one end to peridotites at the other, with

* Mitt. d. Bad. geol. Landesanstalt, ii. Bd., p. 247.

† Proc. California Acad. Sci., ser. 2, vol. iii, p. 47. Tenth Census, vol. xv, p. 725.

the gabbros standing in an intermediate position, so in the Highwoods variation extends from syenites practically devoid of ferro-magnesian minerals to those in which augite becomes the chief constituent, though the basic extreme entirely devoid of feldspar has not been observed by us.

Name Shonkinite. — For this type of rock, then, we propose the name of shonkinite, from Shonkin, the Indian name of the Highwood range, by which name, indeed, it is still called by many, and shonkinite we define as a granular plutonic rock consisting of essential augite and orthoclase, and thereby related to the syenite family. It may be with or without olivine, and accessory nepheline, sodalite, et cetera, may be present in small quantities. The Square Butte rock is thus olivine-shonkinite, with these accessory minerals.

The fine-grained dense porphyritic forms which bear the same relation to shonkinite that trachyte does to syenite are dark to black heavy basalts. They are, in fact, orthoclase basalts, a type which, although so far as we know has not yet been described from European localities, is by no means rare in western America. Besides its occurrence in the Highwoods, and also in other localities in Montana alluded to by Lindgren,* its presence in the Absaroka Range and Yellowstone National Park has been mentioned by Iddings.† Somewhat similar rocks have been also mentioned by Zirkel,‡ who does not, however, discuss this type of basalts in the recent edition of his great work on petrography, so far as we have been able to discover in the absence of complete indexing.

White Rock or Sodalite-syenite. — The petrography of the light-colored inner core of the denuded laccolite has been so completely investigated by Lindgren and Melville§ that a further examination enables us to add but very little to their comprehensive description. The rock is shown to be a

* Loc. cit., p. 50; also Am. Jour. Sci., vol. 45, 1893, p. 289.

† Bull. Phil. Soc. Washington, vol. 12, 1892, p. 169.

‡ Mic. Petrog. Fortieth Par., 1876, p. 225.

§ Loc. cit.

sodalite-syenite, and for purposes of convenience we briefly summarize their results, referring to the original paper for fuller information.

Megascopically the rock when very fresh is nearly pure white, often with a brownish to pinkish tinge, consisting mainly of feldspar, which often reaches 5 millimeters in diameter. Through this are scattered slender, glittering black hornblende prisms which attain at times the same length. It is scarcely sufficient in amount to detract at a distance from the general whiteness of the rock. Small grains of a salmon to brown colored sodalite are also present. The rock is thus rather coarsely granular, and, in fact, of the same size grain as the shonkinite, with which it is so intimately connected.

The microscope shows the following minerals present in the order of their formation: Apatite, hornblende, orthoclase (with some albite), sodalite, and analcite. The hornblende is in slender prisms bounded by m , 110, and b , 010, terminations wanting, frequently twinned on $a(100)$. It is strongly pleochroic c and b , deep brown; a , yellowish brown and absorption very great $b = c > a$. An outer mantle often shows a greenish color (from change into the arfvedsonite molecule? — L. V. P.). Angle $c \wedge c = 13$ degrees; is idiomorphic against the feldspathic constituents. It is closely related to barkevikite, as shown by the analysis quoted later in this article.

The orthoclase occurs in lath-shaped forms and in irregular grains. Those abutting against sodalite show crystal faces. Associated with the orthoclase is a triclinic feldspar referred to albite. The sodalite is found in irregular grains between the feldspars, allotriomorphic in regard to them, idiomorphic against analcite. The latter, which is in considerable amount, was along with the sodalite separated and analyzed. The analcite is thought to be derived from the albite. The rock is calculated from the analysis (given later in this paper) to consist of 66 parts of feldspar, 23 of hornblende, 8 of sodalite and 3 of analcite.

In addition to these facts we have only to add that in the additional material studied by us we have detected a small amount of nephelite, which is being changed by borders, bays, and tongues of analcite eating into it and thus suggesting an additional origin for the analcite; also considerable natrolite is sometimes present. Its fibrous masses are secondary after sodalite and at times it completely replaces it.

GENERAL PETROLOGY OF SQUARE BUTTE.

The facts which have already been given in regard to Square Butte show it to be one of the most remarkable and interesting occurrences of an igneous rock that has been described and from a petrologic point of view one of the most important; for while the differentiation of a molten magma as a factor in the formation of igneous rocks is now regarded by the majority of petrologists as an established fact, it is also true that the theory has been founded almost entirely upon inferential proof and by the exclusion of other hypotheses. The direct proofs which have come under observation have not been all that could be desired, and some of them indeed, as in the case of mixed dikes, have had more than one interpretation.

In the case of Square Butte, however, the proof of differentiation is unequivocal and direct, for in no other rational way, we believe, would it be possible to explain the disposition of the rock masses, the cone-in-cone arrangement of the two differing masses of intruded igneous rock, so unlike in chemical and mineral composition, yet geologically a unit and absolutely homogeneous in granularity and texture and so perfect in continuity of structure and platy parting.

It is therefore a matter of interest to compare the chemical and mineral composition of these two rocks, the syenite and shonkinite, with one another, and see, so far as possible, how and under what conditions the differentiation has taken place. For this purpose the analyses of the two rocks are here compared:—

	Rock analyses.			Chief oxides to 100.		Molecules.	
	A	B		A ¹	B ¹	A ²	B ²
SiO ₂	56.45	46.73	SiO ₂	57.83	48.36	65.61	49.27
TiO ₂	0.29	0.78	Al ₂ O ₃	20.57	10.40	13.62	6.27
Al ₂ O ₃	20.08	10.05	FeO	5.72	11.78	5.39	10.02
Fe ₂ O ₃	1.31	3.53	MgO	0.64	10.01	1.10	15.28
FeO	4.39	8.20	CaO	2.19	13.68	2.65	14.84
MnO	0.09	0.28	Na ₂ O	5.75	1.88	6.33	1.82
MgO	0.63	9.68	K ₂ O	7.30	3.89	5.30	2.50
CaO	2.14	13.22		<u>100.00</u>	<u>100.00</u>	<u>100.00</u>	<u>100.00</u>
Na ₂ O	5.61	1.81					
K ₂ O	7.13	3.76					
H ₂ O	1.77	1.24					
P ₂ O ₅	0.13	1.51					
Cl	0.43	0.18					
	<u>100.45</u>	<u>100.97</u>					
O = Cl	0.10	0.04					
Total	<u>100.35</u>	<u>100.93</u>					

In the above table the analysis of the syenite by Melville is given under A; that of the shonkinite by Pirsson is repeated under B. For purposes of more easy comparison they are repeated under A¹ and B¹, with the non-essential elements omitted, the ferric iron reduced to ferrous, and the whole brought to 100. This at once brings out the most important chemical characteristics of the shonkinite, its very high iron, lime, and magnesia, properties which show its difference from the typical syenites and its approach to the basaltic and lamprophyre groups. In A² and B² are given the percentages of molecules in the rocks derived from the oxygen ratios. The percentages by molecules gives in general a much clearer idea of the chemical composition of a rock than that by weight, because it shows more correctly its capacity for forming minerals.

From the above table it is seen at once that the magnesia shows the greatest differentiation, then the lime, and then iron. The relative proportion of the alkalis to each other and to alumina is about the same in each; they vary somewhat, it is true, but the variation is insignificant compared with

that of the bivalent oxides. The tendency of variation, then, has been for the lime, iron, and magnesia molecules toward the outer cooling surface, while the alkalis and alumina have remained a constant, or if we imagine the silica to remain a constant, they have moved inwardly. It is also clear that the bivalent oxides have not kept a nearly constant ratio, for magnesia is much more concentrated than iron.

Of course, this implies that the molten mass before intrusion into the laccolite cavity was of uniform composition; that one liquid mass of one kind was not succeeded by another of different composition. The very regular and symmetric arrangements of the parts, the absence of all inclusions or "schlieren," the cleanness of the zonal edge, together with the common properties already pointed out, utterly preclude this idea. There are, indeed, places in the Highwoods where intruded masses show further movements after differentiation has taken place, with the result of remarkably banded and streaked rocks, whose very occurrence shows that such was not the case at Square Butte.

We are, indeed, forced to conclude at every step that the mass was originally homogeneous, and that differentiation took place by the diffusion of the bivalent oxides toward the outer surfaces.

It would add greatly to the value of the results here presented if we could know or could obtain the composition of the original magma in which the differentiation took place. This, however, cannot be done by comparing the masses of the two rocks, because, although it is probable that the amount of syenite now present represents pretty nearly the original one—that is, that there has been only a small erosion of that rock—the case is quite different with the shonkinite, a very large part of which has been carried away; hence, not knowing the relation of the two masses involved, we cannot estimate the composition of the original magma. It is evident, however, that it must have been between the syenite and shonkinite.

Shonkinite, however, occurs in large bodies in the neigh-

borhood of Square Butte and elsewhere throughout the Highwood range, while rocks closely related to it in chemical and mineral composition are found in the form of dikes, extruded lavas, and breccias. Throughout the district what may be called acid or highly feldspathic rocks play but a subordinate rôle. In view of these facts, we are inclined to believe that the composition of the original magma approximated more closely to shonkinite than to the syenite.

It will be seen, therefore, that Square Butte presents in a demonstrative way the same idea that Brögger inferentially deduced and presented as the explanation of the processes of differentiation by which the varied rocks of the region of South Norway have been formed.*

Recently Harker † has described an interesting occurrence of a gabbro massif, which grows steadily more basic or richer in the ferro-magnesian minerals as the outer boundary is approached. Harker explains this occurrence by pointing out that the order of concentration of the minerals is the same as the order of their crystallization, and hence accounts for the differentiation as a process of crystallization. Square Butte is also more basic as we approach the outer boundary, but the transition occurs abruptly, so to speak, or within such a narrow zone that it practically does. It is evident, however, that differentiation did not take place at Square Butte as a process of crystallization, but in a liquid magma before any crystallization occurred. This is rendered quite evident, since none of the ferro-magnesian minerals of the shonkinite are found in the syenite. The only one, indeed, which is found in the syenite is the barkevikite-like hornblende, while in the shonkinite are found iron ore, biotite, olivine, and pyroxene. Thus Square Butte affords a striking confirmation of the ideas recently expressed by Brögger in his remarkable work on the basic rocks of Gran.‡

It is a matter of some interest here to compare the com-

* *Zeit. für Kryst.*, vol. xvi, 1890, p. 85.

† *Quart. Jour. Geol. Soc.*, vol. 1, 1894, p. 311.

‡ *Quart. Jour. Geol. Soc.*, vol. 1, 1894, p. 15.

position of the augite of the shonkinite, by far its most prominent constituent, and the hornblende of the syenite from Melville's analysis.

	Barkevikite.	Augite.
SiO ₂	38.41	49.42
TiO ₂	1.26	0.55
Al ₂ O ₃	16.39	4.28
Fe ₂ O ₃	3.75	2.86
FeO	21.75	5.56
MnO	0.15	0.10
MgO	2.54	13.58
CaO	10.52	22.35
Na ₂ O	2.95	1.04
K ₂ O	1.95	0.38
H ₂ O	0.24	0.09
	99.91	100.21

The result of the increase of magnesia and lime shows itself in the change in composition of the dark mineral. The iron shows a movement in the opposite direction; in the syenite it is all found in the hornblende; in the shonkinite large quantities had been used for the iron ore and olivine, and to some extent for the biotite before the augite began crystallizing; hence it is not so prominent as in the barkevikite.

In general, however, the difference is of like kind with that shown by the mass analyses of the rocks and shows clearly how the composition of the prominent dark mineral is a function of the magma in which it is formed. That minerals indeed are so often conditioned by the magma in which they are formed is without doubt the fact that has given to some the idea that definite mineral molecules individualized as such can exist in the molten magma.

Recently Johnston-Lavis * has formulated a theory for the different composition of igneous rocks occurring at the same eruptive centre by supposing that the body of molten magma which gave them birth was originally homogeneous, but

* Natural Science, vol. iv, February, 1894.

became of different composition on its outer margin by fusion and absorption of the country rocks with which it came in contact.

Whether this is ever so or not is fairly a matter for argument. That such a process cannot, however, be appealed to as a general explanation is clearly shown at Square Butte, where the outer margin, as already shown, is much more basic than the interior, and yet the magma has been intruded into sandstones — that is, rocks much more acid than the original magma.

The singular white band which has been previously described as occurring on the south side of Square Butte presents on a small scale the same process of differentiation between the syenite and shonkinite. We believe that it represents what may be called a residual differentiation — that is, that after the main process had already taken place and the outer margins of the laccolitic cavity were filled with that magma which was later going to cool and crystallize into shonkinite this further differentiation took place in the shonkinite fluid.

The latter, probably owing to increasing viscosity, was not able to permit the white band fluid to pass in by diffusion to the main body of the syenite and it therefore remained parallel to the transition zone of the two principal masses.

It will be noticed that a section passing from the centre to the south of Square Butte passes twice through white feldspathic and twice through dark augitic rock, if we take the white band into consideration. Further, that these various layers have a concentric arrangement with respect to each other, and hence one sees that Square Butte presents on a huge scale a rude parallel to those spheroidal masses which sometimes occur in granites and diorites, and which are often remarkable for the regular concentric arrangement of spherical shells of varying composition.

Bäckström* has sought to explain certain cases of such spheroidal masses as portions of a partial magma separated

* Geol. Foren. Förh., Stockholm, Bd. 16, 1894, p. 128.

out in the liquid state from a mother liquor, in which, by sinking temperature, they are no longer soluble.

Bäckström has expanded this idea and sought a general explanation* for the differentiation of igneous magmas in a process of "liquation," by which is meant that an originally homogeneous magma by sinking temperature becomes unstable and separates into two or more fluids which are insoluble in each other — that is, non-miscible. It seems to us that the concentric arrangement of parts and the clear and sharp line of division between them at Square Butte point very favorably to this view as an explanation. Bäckström, however, expresses himself as strongly against the idea of "diffusion," by which we suppose is meant the diffusion of the basic oxides toward the outer cooling surfaces. That such diffusion, however, can take place is clearly shown at Square Butte, where it has. In any case a diffusion of some kind must take place or the magma would remain homogeneous. We do not see, indeed, that Bäckström has advanced any reason which would prove that these two ideas, diffusion and liquation, necessarily exclude each other. We do not see, in fact, why both may not be operative.

As a matter of fact, the more that the differentiation of igneous rocks is studied the more evident it becomes that no one simple process will explain all cases, but that to produce such results a variety of factors must be included, any one or all of which may operate to produce a given phenomenon. Such, for example, may be pressure, change of temperature, convection currents (which are shown by the "flow structure" and parallel arrangements of phenocrysts on the margins of intruded masses), diffusion of certain oxide molecules toward cooling surfaces, liquation and crystallization. The operation of these on molten silicate magmas is as yet but little understood and much more must be done and learned before any generally satisfactory theory for differentiation can be advanced.

* Jour. of Geol., Chicago, vol. i, 1893, p. 773.

Whatever may have been the causes at work at Square Butte, two things at least are evident: that the basic oxides concentrated toward the outer edges and that the changes which produced this took place very slowly and with extreme regularity, allowing the differentiation to be very complete and thorough.

SUMMARY.

Square Butte is a laccolite which has been intruded in Cretaceous sandstones. After the intrusion differentiation took place in the liquid mass, the iron, magnesian, and lime molecules being greatly concentrated in a broad exterior zone, leaving an inner kernel of material richer in alumina, alkalies, and silica. This crystallized into a sodalite-syenite, while the outer mass formed a basic granular rock composed essentially of augite and orthoclase, to which the name of shonkinite has been given. After solidification the cooling developed a fine platy structure throughout the mass parallel to the form of the laccolitic cover. Since then erosion has removed the cover, laying bare the laccolite and dissecting it, so that its structure is clearly brought out.

Owing to the erosion and the platy parting, the broad marginal zone of shonkinite has been carved into a wide band of singular monoliths which extends around the mountain on its lower slopes.

PETROGRAPHY OF THE ROCKS OF YOGO PEAK.*

By L. V. PIRSSON.

THE rock mass of Yogo Peak,† and the different rock varieties into which it is differentiated have already been described by Mr. Weed and the writer.‡ In that article only brief petrographic details were given, sufficient to make clear the discussion of the analyses and the facts bearing on theoretic petrography which comprised its essential features. It is here proposed to treat these types in more detail especially those points which are of interest to petrographers. The discussion of the facts from a standpoint of general petrography is deferred to the latter part of this work.

SYENITE OF YOGO PEAK.

That portion of the Yogo Peak stock which may be most properly classified as a syenite comprises the eastern shoulder of the elevated mass. The rock possesses a platy parting which causes it to split readily and form piles of *débris* above which project low and much-jointed exposures of the rock in place. The joint blocks are short, stout rhomboids, or heavy plates a foot or so long. They are very hard and tough, ring sonorously under the hammer, and are broken with difficulty, the rock being unaltered and fresh.

* Abstract from *Geology and Petrography of the Little Belt mountains, Montana*, by W. H. Weed and L. V. Pirsson, 20th Ann. Rep. U. S. Geol. Survey, Part III, pp. 471-488, 1900.

† Yogo Peak is one of the most prominent of the Little Belt range, rising to 9000 feet in elevation. It consists of a mass or stock of granular igneous rock intruded in Paleozoic limestones and other bedded rocks. At the contact the igneous rock is very dark and basic and is the shonkinite mentioned, it grades into a more feldspathic zone of monzonite, which in turn passes into the still more feldspathic syenite, the first type described. The petrography of these three types is discussed in this abstract. — EDITOR.

‡ Amer. Jour. Sci., vol. 50, 1895, p. 467.

On a freshly fractured surface the rock appears evenly granular, of moderately fine grain, and is compact in character and with few miarolitic cavities. The color is a medium gray with a pinkish tone. Examined with the lens, it is seen to be chiefly composed of light-colored feldspar, dotted with small, dark, formless spots of green pyroxene or hornblende.

The microscope shows the following minerals to be present: apatite, titanite and iron ore, pyroxene, hornblende and biotite, orthoclase, oligoclase, and quartz. The apatite and titanite are of the usual characters common to such rocks. The iron ore is not abundant and occurs in small grains of about 1 mm. in diameter. The pyroxene is a very pale green diopside and is much cracked and broken up. It frequently appears like a bundle of rods. It is rarely alone and generally occurs in common with a brownish-green hornblende. The two minerals are very frequently found together in stout, ill-shaped crystals from 1 to 2 mm. long, the pyroxene forming a core, surrounded by the hornblende. In such cases the amount of pyroxene is inversely proportional to that of the hornblende. The appearance and association of these two minerals indicate that the hornblende is paramorphic after the pyroxene. The latter rarely occurs alone, while the hornblende frequently does so. Biotite is rare and occurs only as occasional brown pleochroic shreds.

Orthoclase is the predominant feldspar, occurring in irregular masses. A smaller quantity of plagioclase is also present, whose optical characters prove it to be oligoclase. It is more idiomorphic than the orthoclase, frequently or even commonly occurring in rather rectangular elongated laths, and is often surrounded by a mantle of orthoclase. A small amount of interstitial quartz completes the list of minerals.

In structure the rock is hypidiomorphic, but only partly so, as the pyroxene and hornblende are themselves rather ill-formed and irregular, and the tendency is toward an allotriomorphic structure. The average size of grain is about 1 mm.

The analysis given in No. I of the table shows the chemical composition of this rock.

ANALYSES OF SYENITES.

	I.	II.	III.	IV.
Silica (SiO_2)	61.65	59.56	61.73	1.027
Alumina (Al_2O_3)	15.07	17.60	17.45	0.145
Ferric iron (Fe_2O_3)	2.03	2.90	5.94	0.013
Ferrous iron (FeO)	2.25	3.38		0.031
Magnesia (MgO)	3.67	1.87	2.29	0.092
Lime (CaO)	4.61	3.67	4.52	0.082
Soda (Na_2O)	4.35	4.88	3.12	0.070
Potash (K_2O)	4.50	4.40	3.88	0.048
Water (H_2O) at 110°	0.26	1.37	1.16	. . .
Water (H_2O) above 110°	0.41			
Titanic oxide (TiO_2)	0.56	1.22	?	. . .
Chromic oxide (Cr_2O_3)	tr. $x = 0.44$	—	—	. . .
Manganese oxide (MnO)	0.09	0.03	—	. . .
Baryta (BaO)	0.27	?	?	. . .
Strontia (SrO)	0.10	?	?	. . .
Chlorine (Cl)	—	—	—	. . .
Phosphoric acid (P_2O_5)	0.33	?	?	. . .
Sulphuric acid (SO_3)	—	—	—	. . .
Carbonic acid (CO_2)	—	—	—	. . .
Lithia (Li_2O)	tr.	—	—	. . .
	100.15	101.32	100.09	. . .

I. Syenite, Yogo Peak. Little Belt Mountains, Montana. W. F. Hillebrand, anal.

II. Syenite Aakerite type, Vettakollen. So. Norway. H. O. Lang, *Nyt. Mag. for Nat.*, vol. 30, p. 40 (P. Jannasch, anal.).

III. "Syenite," "diorite," "banatite" Hodritsch vale, by Schemnitz, K. von Hauer, *Verhand. k. k. Reichsanstalt*, 1867, p. 82.

IV. Molecular proportions of No. I.

The analysis is that of a syenite with rather high lime, iron, and magnesia for a rock of this group. The mineral and chemical nature of the rock show it to have a somewhat dioritic tendency, and in fact it is closely related to the monzonite group in which the feldspars are equal, that is approximately the plagioclase equals the orthoclase. It is very closely related to certain of the syenites which have been called *Akerites*, as the analysis of one of them tends

to show. Moreover the description of these akërites as given by Brögger,* with their rectangular zonal feldspars, applies closely to this rock. On the other hand, its relation to certain rocks which have been variously placed, sometimes among the syenites, sometimes among the diorites, is shown by the close agreement with the analysis of the rock from the Hodritsch vale near Schemnitz. All these types clearly belong in a group by themselves and, following the proposal of Brögger,† they may well be considered, an intermediate group between the normal syenites and diorites and called *banatites*, after the old name used by Von Cotta. Thus the rock of Yogo Peak, although here called a syenite as, under a broad grouping, according to present ideas of rock classification, it would undoubtedly be so called, would for petrographical purposes be better designated as a *banatite*. Its connection with the monzonite of Yogo Peak as part of a single geologic mass is extremely interesting, as it shows that grouping and connection exhibited by nature itself which Brögger has suggested on theoretic grounds.

By assuming all the alumina in feldspar and taking the equivalent of soda, potash, and lime for it and then assigning sufficient ferrous iron to convert the ferric iron into magnetite we may calculate with pretty close approximation to truth the mineral composition. For the remaining lime, iron, and magnesia are to be divided between pyroxene and hornblende, which is readily done while the excess of silica represents the quartz. This gives

Magnetite	3.1		
Pyroxene	5.4		
Hornblende	12.9		
Anorthite	7.5	Dark	21.4
Albite	37.5	Light	78.6
Orthoclase	27.5		100.0
Quartz	6.1		
	100.0		

* Syenit pegmätit gänge Sud Norwegens, Groth's Zeit. f. Kryst., vol. 16, p. 51.

† Triadischen Eruptionsfolge bei Predazzo.

The average plagioclase would be Ab_3An_1 but as considerable of the albite molecule is doubtless with the orthoclase, the oligoclase present does not average so much soda as this.

Local varieties of the syenite.—Towards the high east shoulder of Yogo Peak which descends to a saddle on the ridge, the talus forming this slope shows a variety of the rock in which the plagioclase diminishes almost to the vanishing point and the rock therefore assumes the character of a normal and typical syenite; in other respects its character is that of the type just described and it cannot indeed in the hand specimen be distinguished from it. The variation is probably local but it has a certain petrologic significance which will be treated of in another place.

At the prospect mining shaft which has been sunk not far from the contact on the south side of Yogo Peak in the igneous rock there occurs a light-colored rock which is another variation of the banatite in that it represents a more dioritic phase; the lath-like plagioclases clearly predominate over the alkali feldspar and form the main rock constituent. It is interesting to note in this variety that the hornblendes although quite compact and appearing on the whole as if original yet occasionally carry interior cores or fragments of pale green diopside. What the exact relation of this diorite-like facies is to the shonkinite and monzonite which are the main rock types of the vicinity could not be learned, as it is not apparent at the surface, but it must certainly be quite limited in amount when compared with them.

MONZONITE.

This name has been applied to a massive igneous rock occurring at Monzoni in the Tyrol which has usually been classified under the syenites, of which it has been considered a variety rich in plagioclase and in the darker ferromagnesian minerals, especially pyroxene. It has been shown in recent years that this type of rock is not confined to the vicinity of Monzoni, but occurs elsewhere in sufficient abundance to warrant the proposition that the name shall no longer

be considered that of a mere variety of syenite but of an independent rock group, of the same order of significance as that of syenite and diorite, to be applied to those rocks in which the alkali and lime soda feldspars are about equally balanced, thus avoiding the difficulties of classifying such rocks either with the syenites or the diorites. * In the former article on Yogo Peak by Mr. Weed and the writer † the latter in the petrographic description showed that the type of rock forming the middle knob of the peak was of unusual character, in which alkali feldspars were of about equal amount with plagioclase, and the name "yogoite" was proposed for this type.

Later, ‡ however, recognizing that "yogoite" is essentially the same rock as that from Monzoni and Predazzo both chemically and in its mineral composition, the name "yogoite" was withdrawn for the older and better known term. Rocks of this character have been found in several localities in Montana and the number of occurrences in this portion of the Rocky Mountain area will no doubt be increased in the future. It can scarcely be doubted also that many types of rocks hitherto placed under diorites or syenites by different petrographers really belong in this general group and that the future will show the type to be a not uncommon one. In the localities so far described at Monzoni and Predazzo in Tyrol, at the Bearpaw Mountains, and here at Yogo Peak and also in the Highwood Mountains in Montana, the rock does not appear geologically alone and independent but is accompanied by more feldspathic types on the one hand and more dark-colored, basic, augitic varieties on the other. It is thus part of a differentiated complex and, considering the very medium chemical character it possesses, as a sort of petrographic mean, this should be expected.

At Yogo Peak the rock occurs most typically and best ex-

* Brögger, *Eruptivgesteine des Kristianiagebietes*, ii, Predazzo.

† *Amer. Jour. Sci.*, vol. 50, p. 467, 1895.

‡ Weed & Pirsson, *Bearpaw Mountains of Montana*, *Amer. Jour. Sci.*, vol. i, p. 357, 1896.

posed at the central one of the three prominent knobs forming the peak. It grades into the banatite variety of syenite, previously described which forms the eastern shoulder on the one hand and into the shonkinite of the western outcrops and exposures on the other.

The rock occurs in short blocks and is very firm and tough. On a fresh fractured surface it is of a rather dark gray with a greenish tone and appears of a medium granularity. It is clearly seen to be somewhat mottled by the contrast between the light colored feldspathic portion and the darker colored ferro-magnesian minerals and recalls in its appearance many diorites; the dark minerals appear to make up half the bulk of the rock. The reflection of light from numerous biotite cleavages of small size is also noticeable.

Under the microscope the minerals seen are iron ore, apatite, biotite, pyroxene, hornblende, plagioclase, alkali feldspars, and quartz.

The iron ore is not present in large amount, but is seen in scattered grains usually attached to pyroxene and biotite. The apatite is not abundant and shows nothing of especial interest.

The pyroxene is a clear pale green diopside of wide extinction angle and rather idiomorphic in form. It is pretty free from inclusions save those of iron ore and apatite; in a few cases some of a brownish substance which may be glass were seen. It is very fresh and unaltered except for its connection with hornblende. It is the most abundant ferro-magnesian mineral.

The hornblende is of the olive-green color usually seen in common hornblende, strongly pleochroic, and is generally seen surrounding or attached to the diopside. It occurs in places penetrating the latter in small flakes or rods, and sometimes the diopside is quite spotted with these bits of hornblende. When in larger pieces it does not have any distinct idiomorphic form and all these facts go to show very clearly its secondary paramorphic character. Nowhere does it show those evidences of primary character which Iddings has so

well described and figured in the intergrowths of hornblende and pyroxene in the diorite of Electric Peak.* An estimate made on the sections places it as being one-tenth of the diopside in amount.

The biotite is pleochroic in tones of pale yellow and olive brown, basal sections are a deep umber brown. It is quite idiomorphic and has the usual apatite and iron ore inclusions.

The plagioclase is rather variable; studies of it according to recent methods show that it is mostly andesine, in small part oligoclase, and even a little albite is present. It occurs in rather broad tabular forms giving in general idiomorphic sections: sometimes it is seen in rather slender laths which are always smaller than the table mentioned above and while they are generally Carlsbad twins they often show no albite twinning or at best but one or two strips; they are invariably of andesine. The larger tables on the contrary always show albite twinning, usually in very fine lamellæ, and sometimes are not Carlsbad twins; they are more irregular in their composition; are sometimes zonally built with basic cores and sometimes consist of varying irregular masses without any regular crystallographic or zonal arrangement, but with the albite twinning passing through as if the crystal were entirely homogeneous. Thus in these crystals while andesine is the most common proportion, they vary through oligoclase to albite.

The alkali feldspar is mostly a soda orthoclase but this contains a microperthite-like intergrowth of another feldspar that is believed to be albite, but it is present in such narrow lamellæ that this could not be proved; moreover it does not show the albite twinning. All that can be safely said of it is that it is another feldspar and not quartz. The intergrowths are not exactly like the usual microperthitic lamellæ of albite but more nearly resemble micrographic intergrowths of quartz and orthoclase; it does not require a very high power to see them clearly.

The calculation of the chemical analysis shows that the

* 12th Ann. Rep. U. S. Geol. Surv. Washington, 1892, p. 606.

total average alkali feldspar has the composition Or_1Ab_1 but the microscope shows that although this may be the sum total there is considerable variability in the manner in which the albite and orthoclase molecules are arranged.

ANALYSES OF MONZONITES.

	I.	II.	III.	IV.	V.	VI.	VI ^a .	VII.
SiO_2	54.42	52.81	52.05	51.00	54.20	52.89	53.0	0.907
Al_2O_3	14.28	15.66	15.02	17.21	15.73	15.58	16.0	0.139
Fe_2O_3	3.32	3.06	2.65	2.41	3.67	3.03	3.0	0.021
FeO	4.13	4.76	5.52	4.23	5.40	4.81	5.0	0.057
MgO	6.12	4.99	5.39	6.19	3.40	5.22	5.0	0.152
CaO	7.72	7.57	8.14	9.15	8.50	8.21	8.0	0.139
Na_2O	3.44	3.60	3.17	2.88	3.07	3.23	3.0	0.055
K_2O	4.22	4.84	6.10	4.93	4.42	4.90	5.0	0.045
$\text{H}_2\text{O} - 110^\circ$	0.38	0.93	0.35	0.63	0.50	0.51	0.5	...
$\text{H}_2\text{O} + 110^\circ$	0.22	0.16						
TiO_2	0.80	0.71	0.47	0.13	0.40	0.56	0.5	...
Fl	...	tr.	...	...	...	...	...	...
Cl	...	0.07	0.24	tr.	...	0.11	...	...
P_2O_5	0.59	0.75	0.21	0.33	0.50	0.47	0.5	...
SO_3	...	tr.	0.02	0.03	...	...	...	...
Cr_2O_3	...	tr.	...	...	...	...	...	...
MnO	0.10	tr.	tr.	tr.	0.70	...	...	...
BaO	0.32	0.24	0.42	0.34	?	0.33	0.3	...
SrO	0.13	0.09	0.28	0.14	?	0.15	0.2	...
Li_2O	tr.	tr.	...	...	...	...	...	...
	100.19	100.24	100.03	99.60	100.49	100.00	100.00	

I. Monzonite of Yogo Peak. W. F. Hillebrand, anal.

II. Monzonite of Beaver Creek, Bearpaw mountains (Weed and Pirsson, *Am. Jour. Sci.*, vol. 50, 1895, p. 357). H. N. Stokes, anal.

III. Monzonite of Highwood Peak, Highwood mountains (*Bull. U. S. Geol. Surv.*, No. 148, p. 154). E. B. Hurlburt, anal.

IV. Monzonite of Middle Peak, Highwood mountains (*Loc. cit. supra*). E. B. Hurlburt, anal.

V. Monzonite of Monzoni (Brögger, *Erupt. Gest.*, Predazzo, 1895, p. 24). V. Schmelck, anal.

VI. Average of above analyses reduced to 100.

VII. Molecular proportions of No. I.

The structure of the rock is a purely hypidiomorphic granular one. There is a strong tendency for the ferro-magnesian elements to be together and also for little areas to occur in

which plagioclase is very abundant, others in which it is nearly absent and unstriated alkali feldspar rules. Thus, while taken in mass the composition of the rock is very homogeneous, on a microscopic scale it is variable and it is hard to bring into the field of the microscope, except with extremely low powers, an area that would be typical of the rock as a whole. The alkali feldspar shows always a tendency to a broad poikilitic character tending to surround the other minerals. An extremely minute amount of interstitial quartz needs no further mention; its rôle as rock component is here without significance.

An analysis of the rock by Dr. Hillebrand is shown in the above table, and with it published analyses of four other monzonites from different localities; the older analyses are full of analytical errors and are not to be trusted; it will be noticed how nearly all these agree and how little any one of them departs from the mean of the whole five given in No. VI. This mean may be taken then as the typical composition of a monzonite, or as expressed in the nearest whole numbers and given in No. VI^a. The feature of this chemical composition is the very medium character expressed throughout; in all respects the monzonites stand as a mean between the different rock groups.

If we make two or three assumptions, as follows, that the biotite is nearly or practically free from ferric iron and agrees with the biotite of Monzoni which has been analyzed, in this regard: that the replacement of magnesia by ferrous iron is similar in the minerals into which these enter and that the amount of hornblende is one-tenth that of diopside as shown by estimates made from the sections, we may calculate from the analysis and the table of molecular proportions given in No. VII the mineral composition of the rock. None of these assumptions is absolutely correct, but all of them must be approximately so, hence the following table, while not absolutely accurate, must represent the composition pretty closely.

Magnetite	5.1	Andesine (An_2Ab_3)	27.2
Biotite	12.1	Soda-orthoclase (Or_1Ab_1)	30.4
Diopside	20.7	Total feldspars	57.6
Hornblende	4.5	Total ferro-magnesian minerals	42.4
Anorthite	11.3		100.0
Albite	30.1		
Orthoclase	16.2		
	100.0		

The amount of the albite molecule present is just sufficient to turn the anorthite into the andesine demanded by the microscopic study and have enough left to convert the orthoclase into a soda orthoclase where the relations are as 1:1 and this is a very common ratio for soda orthoclase, as indeed on chemical grounds we should be obliged to expect. The calculation shows also that the plagioclase and alkali feldspar present are equal and again shows the impossibility of classifying these rocks logically either as syenites or diorites. The large proportion of ferromagnesian minerals present, forming two-fifths of the whole, also shows the middle position occupied by this type.

SHONKINITE.

This name has been given to dark-colored basic granitoid rocks consisting chiefly of orthoclase (or alkali feldspar) and augite, but in which unlike the syenites, which are feldspathic rocks, the augite predominates producing an augitic or as one might say a gabbroid rock. Besides these chief components, olivine, biotite, and iron ore among the dark-colored minerals and plagioclase among the light-colored ones may be present as accessory components in considerable amount, — but the orthoclase and augite are in all cases the determinant minerals. This type of rock is closely related to theralite in that both are dark-colored basic augitic types and both are apt to occur associated with other types of rocks rich in alkalis, but theralite, the granular plutonic equivalent of the tephrites, has plagioclase and nephelite as its determinant white minerals.

The first shonkinite described was that from Square Butte

in the Highwood mountains by Mr. Weed and the author* and later the occurrence at Yogo Peak was briefly given.† This account it is now proposed to supplement by further details and to mention another occurrence in this district. Besides these occurrences in the Little Belt and Highwood mountains, shonkinite has been described from localities in the Bearpaw mountains,‡ and it appears, as will be shown later, to occur at Monzoni in the Tyrol, and doubtless other localities will be found as knowledge of the type becomes better known and petrographic research progresses.

SHONKINITE OF YOGO PEAK.

At Yogo Peak the shonkinite forms the rock masses of the western end, abutting against the sediments and it also occurs about four miles northeast on the ridge running out in that direction from Yogo Peak. Here again it is found in contact with the limestones, while to the south it is bordered by the acid feldspathic rocks. This is at the head of one of the head branches of Running Wolf Creek. Whether the shonkinite forms everywhere an exterior zone of this great intrusion in the sedimentary beds as it does at Square Butte in the Highwood mountains and in other localities seems rather doubtful and cannot be positively told from the lack of exposures, but it certainly does in part, and wherever it appears in connection with this intrusion it is in its proper position as the exterior portion of a differentiated mass.

The shonkinite rock does not possess the thick, platy parting that prevails in the monzonite and syenite to the east, but has an exceedingly massive character, giving rise to bold, heavy crags, often of curious shapes, which rise abruptly from small grassy plots lying between them. The rock is exceedingly tough and breaks under the hammer with great difficulty. On a fresh fracture it is of a very dark stone color,

* Bull. Geol. Soc. America, vol. 6, p. 389, 1894.

† Am. Jour. Sci., vol. 50, 1895, p. 467.

‡ Weed & Pirsson, Bearpaw Mountains of Montana, Amer. Jour. Sci., vol. i, 1896, p. 351.

and at first glance recalls many coarse, dark gabbros. On inspection it appears that the quantity of ferro-magnesian minerals is very large, and the eye is caught by the reflection of numerous plates of a dark brownish biotite, which average several millimeters in diameter. With the lens a great abundance of small augites are also seen in the feldspathic constituent.

At places and especially towards the contact there is considerable variation in the grain of this type; it sometimes occurs very much finer than the normal type mentioned above, and on the other hand at the extreme west end of the peak a variation is found that forms large, irregular masses, the rock being noticeable for the very large, spongy, biotite crystals which it carries. These biotites are at times 1 cm. across a cleavage face. They are made up of a number of smaller, nearly similarly oriented individuals mixed in with other constituents. Although the mica is really subordinate in amount to the other minerals, it has the appearance of being predominant, and the rock seems at first glance to be almost wholly made up of these coarse biotite crystals and has a very coarse-grained, curious appearance. Examination with the lens shows that although the biotite thus appears so important it is merely because the crystals reflect the light from their cleavage surfaces and thus stand out more prominently than the others; moreover they are very poikilitic and filled with augite grains. Thus the actual amount of biotite is less than that of either augite or orthoclase.

Under the microscope the minerals noted are iron ore, apatite, augite, hornblende, biotite, olivine, plagioclase, and soda-orthoclase.

Iron ore as an actual component of the rock is almost entirely wanting; in one phase a few scattered grains surrounded by coats of biotite were observed, but in the other sections representing different phases and areas of the shonkinite mass it may be said to be entirely wanting. This is a very striking feature for so dark and basic a type, which, as the analyses show, possesses considerable of the oxides of iron;

it is therefore clear that it has gone into the ferro-magnesian minerals present, and the green color and character of much of the biotite indicates that it must approach lepidomelane in composition. It should be stated, also, that a very small amount of iron ore from the olivine resorptions, to be presently described, is also present, but this is, in a way, secondary and confined to these occasional minute areas.

The apatite present in short, stout crystals shows nothing of especial interest. The amount of phosphoric anhydride in the analysis proves that two and three tenths per cent is present, while the fluorine shows it to be a fluor-apatite. The augite is a pale greenish diopside-like pyroxene of a very wide extinction angle. The prismatic cleavage is well developed, but it shows no other, and no trace of any diallage-like character. It is quite idiomorphic, especially in the prismatic zone, being bounded by the faces $a(100)$, $m(110)$, and $b(010)$ which have generally about an equal development. The ends are less well developed, and are apt to be rounded off, the habit is short, thick, columnar. It contains inclusions of biotite, less rarely of glass or iron ore; these inclusions are infrequent. In size the crystals vary from one-tenth to one mm.

Hornblende is not common, and its character and associations are such as to lead to the belief that it is secondary as described under the monzonite of Yogo Peak, its color, lack of definite form, association with pyroxene are similar, but it is rather less in amount.

Olivine and its resorption bands.—The olivine, in the most basic type, that is, the one containing the coarse poikilitic biotite, is mostly very fresh and clear, but in a few places altered to a yellowish-red micaceous substance, one of the well-known alterations of olivine which need not be further mentioned. The olivine has no good crystal outline, but is in irregular masses. It has as inclusions shreds of mica, sometimes an ore grain, and occasional little darker shadow-like spots which, when examined with very high powers, are seen to be skeleton magnetites which present

wonderful patterns of intricate grating structures. They resemble somewhat similar growths which have been previously described by other petrographers.

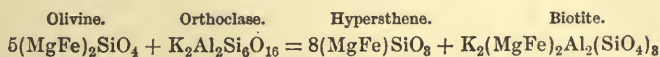
The most interesting thing in regard to the olivines is the resorption phenomena they show. In the more basic and coarse-grained phase they are quite unaltered except that they seem somewhat rounded and where they come against alkali feldspar there is generally a band of green mica separating the two. From this character they pass, in other phases of the shonkinite, into types which are surrounded by zones as is often the case in gabbros. The zones, however, are of somewhat different character from those seen in the gabbros. Here the olivine is surrounded by, first, a band of granules of a mineral of high refraction and rather low birefringence, whose general characters indicate it to be enstatite; the granules are too small in size and confused for positive identification, but this also seems most probable considering the composition of olivine. Next to this comes a band of green biotite, and then the feldspar. The iron in the olivine separates out as iron ore in black grains. This process goes on until no olivine is left at all; only a yellowish mica-like substance dotted full of ore grains shows where the core of the original crystal was. From this stage they may be traced gradually by unaltered pieces of olivine into the unchanged crystals.

But the most interesting point in regard to this change is that it is directly proportional to the amount of feldspar which the rock contains. In the most basic, least feldspathic type of shonkinite the olivines as noted above are unaltered, or surrounded only by a band of biotite where they touch the feldspar; in the more feldspathic types they begin to be surrounded by the resorption bands, but there is generally some olivine substance left, though not always. In the *monzonite*, a much more feldspathic phase of the Yogo Peak mass, these resorptions of olivine occur but they are always resorptions; no olivine substance is seen and they are, moreover, not nearly so common. In the *syenite* (banatite) certain groupings of iron ore and biotite suggest the same thing, but

are not conclusive. It is indeed interesting as a speculation as to whether these olivines were formed before differentiation took place in the mass or after it.

The resorption zones, or "reaction rims" as they have been called, which occur around olivines in the plagioclase rocks have been so well described and their origin discussed * that they need no further mention here, but it may be said that the idea that they could have been formed in the shonkinite under discussion by any dynamic metamorphic processes is not tenable for a moment; it does not even need to be discussed — we are dealing with fresh rocks of a recent geologic period, breaking up through unaltered sedimentary beds.

When we consider the chemical composition of the minerals involved, the cause and character of these resorption, or "reaction," phenomena in the shonkinite become quite clear. If we consider that out of the original magma olivine was one of the first minerals to separate, it was because a mineral of that composition was capable of forming, was insoluble in the resulting and residual magma, or capable of existing in it. As the process of crystallization proceeded, however, and the pyroxene, biotite, etc., crystallized out, the residual magma became richer in alkalis and alumina until it eventually solidified as alkali feldspar. When this stage was reached the olivine was no longer insoluble in the molten feldspathic magma and redissolving and the magma crystallizing, the following reaction took place:



That is, the olivine and orthoclase give rise to hypersthene and biotite, and very naturally the hypersthene, the mineral richest in magnesia, lies next to the olivine, while the biotite, rich in alkali and alumina, lies next to the feldspar.

Thus it is very easy to see why on purely chemical grounds the formation of such zones and their composition may be both expected and explained.

* Rosenbüsch, *Mass. Gest.*, 1895-6, p. 314.

It is to be noted that lime, which plays such an important part in the zones around the olivines in the gabbros, is entirely absent in the above. In one or two cases slender needles were seen in the outer zone, and it may be that lime has been present and a little hornblende formed as in the gabbros. This is exceptional in the shonkinite and not the rule.

Feldspars. — The feldspars in the shonkinite are somewhat variable, especially the plagioclase. This is sometimes present and sometimes wholly absent, and this within small areas, even within that of an ordinary thin section.

It is usually in the form of laths sometimes very small and narrow, others broader and more columnar. It varies from interior cores as basic as a labradorite Ab_3An_4 to outer rims of andesine Ab_5An_3 ; both albite and Carlsbad twins are generally present. The noticeable feature of this plagioclase is its strong idiomorphic character, and this is especially noticeable when it lies imbedded in the soda orthoclase. In some places within a very minute area a very considerable quantity of these plagioclase prisms will be heaped together surrounded by broad regions quite destitute of them. Its total amount is small, and considered altogether it plays only the rôle of an accessory constituent. It seems to depend on the relation between pyroxene and biotite to some extent; thus in the more basic phases where augite is very abundant and its prisms thickly crowded, the plagioclase is almost wholly wanting because the lime has all united with the magnesia and iron in its production, while in those areas where it is not so common the magnesia and iron combined with alumina and potash to form biotite and this permitted the lime to enter into plagioclase with the soda.

The alkali feldspar ranks with the augite as the most important rock constituent. In sections perpendicular to the obtuse positive bisectrix, that is approximately parallel to $b(010)$, the basal cleavage is easily seen and is usually good; at times a cleavage crosses this at 64° , which is probably parallel to the prism, a not unusual phenomenon in

alkali feldspars: this gives the direction of the vertical axis and enables the section to be oriented, and it is then found that the extinction lies 10° in the obtuse angle, that is, is positive, and therefore the feldspar is a soda orthoclase. This is shown also by its watery, moiré appearance and other phenomena which show that it is not a simple compound.

Chemical composition. — To show the chemical composition of the shonkinite there is given the analysis which has been made by Dr. Hillebrand. Also some analyses of these rocks from other localities are included and these all show the characteristics of the type — rather low silica, low alumina, high iron, lime and magnesia, with moderate alkalies and the potash predominating over soda. In No. V. is given the average of the first three analyses, and this may be taken as representing the typical composition of shonkinite; from it all of them vary but little. The shonkinite magma is that which is characteristic of the class of rocks which have been called lamprophyres. That this magma exists in other localities in a different mineralogic, structural, and geologic form is shown by the comparison of the analyses given in VII and VIII, the former a thick intrusive sheet, the latter of a dike. The relation between shonkinite and absorakite has been already noted by Iddings.* In No. VI is given for comparison the analysis of a rock described by Lawson † under the name of “malignite.” Mineralogically it is closely related to shonkinite, in that pyroxene and orthoclase are the prominent constituents; it differs in the presence of nephelite and in the character of the pyroxene which is ægirite-augite, and these differences are caused by the larger amount of alkalies and especially of soda. Rosenbusch ‡ places it under the shonkinites, including both in the therallite family.

* Jour of Geol., vol. iii, p. 953, 1895.

† Bull. Dept. Geol. Univ. Cal., vol. i, March, 1896, pp. 337-362.

‡ Mass. Gesteine, 3d ed., 1895-6, p. 1303.

ANALYSES OF SHONKINITES.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO ₂	48.98	50.00	46.73	50.43	48.90	47.85	50.82	48.36	0.813
Al ₂ O ₃	12.29	9.87	10.05	10.21	11.07	13.24	11.44	12.42	0.119
Fe ₂ O ₃	2.88	3.46	3.53	11.57	3.32	2.74	0.25	5.25	0.018
FeO	5.77	5.01	8.20		6.33	2.65	8.94	2.48	0.080
MgO	9.19	8.31	9.25	5.58	9.06	5.68	14.01	9.36	0.229
CaO	9.65	11.92	13.22	14.82	11.59	14.36	8.14	8.65	0.173
Na ₂ O	2.22	2.41	1.81	1.48	2.15	3.72	1.79	1.46	0.036
K ₂ O	4.96	5.02	3.76	3.70	4.55	5.25	3.45	3.97	0.052
H ₂ O - 110°	0.26	0.17	1.24	0.87	1.13	2.74	0.58	5.54	0.031
H ₂ O + 110°	0.56	1.16							
TiO ₂	1.44	0.73	0.78	undet.	0.98	...	0.59	1.18	0.017
P ₂ O ₅	0.98	0.81	1.51	0.70	1.10	2.42	0.20	0.84	...
SO ₃	...	0.02	...	...	...	...	...	...	...
CO ₂	...	0.31	...	0.52	...	...	...	...	...
Cl	...	0.08	0.18	...	...	...	...	...	...
Fl	0.22	0.16	...	...	...	...	...	...	...
Cr ₂ O ₃	trace	0.11	...	...	...	...	0.03	...	...
NiO	...	0.07	...	...	...	...	...	...	...
MnO	0.08	trace	0.28	...	...	...	0.19	0.13	...
BaO	0.43	0.32	?	...	...	...	0.06	0.29	...
SrO	0.08	0.07	?	...	...	...	...	...	...
Li ₂ O	trace	trace	trace	...	...	...	...	...	...
	99.99	100.01	100.54	99.88	100.18	100.65	100.49	99.93	...
O = Cl, Fl	0.08	0.08	0.04						
Total	99.91	99.93	100.50						

I. Shonkinite, Yogo Peak, Montana. W. F. Hillebrand, anal.

II. Shonkinite, Bearpaw mountains, Montana (Weed and Pirsson, Amer. Jour. Sci., vol. I, 1896, p. 360). H. N. Stokes, anal.

III. Shonkinite, Square Butte, Highwood mountains, Montana (Weed and Pirsson, Bull. Geol. Soc. Am., vol. 6, p. 414. 1895). L. V. Pirsson, anal.

IV. Shonkinite, Monzoni (Lemberg, Zeitschr. d. deutsch. Geol. Gesell., 1872, p. 201). Lemberg, anal.

V. Average of I, II, and III.

VI. Malignite, Poohbah Lake, Ontario. (Lawson, Bull. Geol. Dept., University of California, vol. I, No. 12, p. 350). F. L. Ransome, anal.

VII. "Lamprophyre." Between South Boulder and Antelope Creeks, Montana (Merrill, Proc. U. S. Nat. Museum, vol. xvii, p. 670, 1895). L. G. Eakins, anal.

VIII. Absorakite dike, south of Clark's Fork river, Wyoming (Iddings, Jour. Geol., vol. iii, p. 938, 1895). L. G. Eakins, anal.

IX. Molecular proportions of No. I.

Structure and classification. — The structure of the Yogo Peak rock is purely hypidiomorphic granular and it has all the characteristics of a plutonic rock. The most striking and dominant microscopic feature is the poikilitic character of the orthoclase which occurs in broad masses, enveloping the other minerals, and evidently the latest product of crystallization. Lawson* mentions it as being also a characteristic of malignite.

From a consideration of the molecular proportions given in No. IX. of the table of analyses with the results of the study of the thin sections it is estimated that the rock contains on the average in percentages by weight:

Pyroxene	35
Biotite	18
Olivine	7
Hornblende, apatite, etc. . . .	5
Andesine	10
Soda orthoclase	25
	100

This, of course, is not accurate, but the control is sufficient to make certain that the variation cannot be more than a per cent or two either way in the more doubtful constituents.

A mere inspection of the above table shows that this rock cannot be classed with existing rock groups, and that its erection into a new group is justified. But its occurrence in other localities and the acceptance of the group by other petrologists are already matters of history and render any further comment on this point superfluous.† It must be stated, however, that the persistent appearance of quantities

* Loc. cit.

† In his review of the original paper on Yogo Peak by Mr. Weed and the writer, Neues Jahrbuch, 1896, vol. 2, p. 442, H. Behrens quotes none of the analyses, omits all mention of the presence of orthoclase in the shonkinite, mentions especially the kind of plagioclase, states with emphasis that it resembles gabbro, and thus produces a totally false impression that only an ordinary gabbro had been described and decorated with a new name—an idea which any one may see is patently wrong by reading the original description and observing the analysis.

of biotite in all these cases, due doubtless to the large amount of MgO and K_2O in the magma renders this mineral a much more constant feature of the rock than was supposed would be the case when the original specimen from Square Butte was described.

Shonkinite at head of Running Wolf Creek. — This occurrence has already been mentioned in the description of the Yogo Peak mass. It has also been studied in thin section, and excepting the fact that none of it has been seen to carry any plagioclase and that the soda-orthoclase is a little more abundant, it so exactly resembles the type already described that no further mention is necessary.

SHONKINITE OF OTTER CREEK.

Besides the occurrence of shonkinite at Yogo Peak there is another in the region of the Little Belt Mountains which deserves a brief mention. It forms the large heavy mass intruded in the upper carboniferous beds on Little Otter Creek about two miles or so above its junction with the main Otter stream. The mass is exposed at least three hundred feet above the creek, and the outcrops extend in a long line of very columnar exposures suggesting a sheet which must be extremely thick. The road quarry at one point has exposed quite good fresh material.

In the hand specimen the rock is very dark gray and moderately fine grained, the components running from 1 to 2 mm. in diameter. In the section it shows the same minerals mentioned above for the Yogo Peak shonkinite, but the amount of olivine which is very fresh and has no reaction rims is considerably greater, while biotite is much less. The amount of andesine is also less, only an occasional minute prism being present. The orthoclase, as usual, cements the other minerals. The rock, in fact, so closely resembles the description already given that it needs no further mention.

MISSOURITE, A NEW LEUCITE ROCK FROM THE HIGHWOOD MOUNTAINS OF MONTANA.

By WALTER H. WEED AND LOUIS V. PIRSSON.*

(From Amer. Jour. Sci. (4) vol. 2, pp. 315-323.)

THE Highwoods form one of the isolated mountain groups of central Montana which rise like islands from the great treeless plains stretching eastward from the slopes of the Rocky Mountain Cordillera, and forming the great basin of the Missouri River. They consist of a group of extinct, greatly eroded volcanoes, and the elevations which now compose the area are formed chiefly of tuffs, breccias, and lava flows resting on Cretaceous sediments, together with intruded stocks or cores of massive granular rocks which represent the former centers of volcanic activity and from which great numbers of dikes radiate outward in all directions.†

In the preparation of a report on the geology of this mountain group it has been found that the body of granular rock forming the core at one of the denuded volcanic centers is composed of a new rock type whose petrologic character is of exceptional interest. As the type, moreover, proves to be of great importance to systematic petrography, it has been thought best to present a brief account of the rock and its mode of occurrence, a more detailed description and the discussion of its geological and petrographical relations being reserved for the report in preparation.

* Field geology and collection of material by W. H. W.; petrography by L. V. P.

† A sketch of the geological features of the region, with a geological map, has been published by the authors. Bull. Geol. Soc. America, vol. vi, p. 389, 1895.

The stock or core is situated at the head of Shonkin Creek, a large stream draining the northern part of the mountains. The headwaters of this stream have cut deeply-trenched channels through the mountains and have exposed the granular rock. The region, although mountainous, is almost devoid of timber. Smooth grassy slopes with occasional low rock exposures generally prevail.

Geological occurrence. — The new rock type described forms a stock of granular rock intrusive in Cretaceous shales and in the fragmental volcanic material which overlies them, both being highly altered near the contact with the igneous mass. These inclosing rocks are cut by a multitude of dikes, radiating from the core as a center and forming the most conspicuous feature of the surrounding country.

The igneous rock forming the stock constitutes an irregular mass $2\frac{1}{2}$ miles long and in places half as wide. Where covered by the sedimentary strata, the structure simulates that of a laccolith, but careful study showed that the intrusion is not of this character. The igneous rock was in part intruded between the sedimentary rocks and the volcanic breccias which overlaid them, and in part injected along the bedding planes of the sedimentary strata at the edges of the stock. At the south end of the core a coarse agglomerate of massive rock represents the filling of a vent of a volcanic throat, the material of the blocks and cement varying greatly in granularity but consisting essentially of the same type composing the main body of the core.

Constituting beyond all doubt a geological unit, the rock mass of this volcanic stock varies considerably both in coarseness of grain and in the proportion of its constituent minerals. The specimen selected for description and analysis represented the coarsest-grained and freshest variety observed.

The rock seldom forms conspicuous exposures; near the contact it is sometimes weathered into castellated masses and pinnacles, but the usual outcrop is low and hidden by the débris blocks into which the rock ordinarily weathers. Platy parting was observed near the contact, but elsewhere the fracture is massive and determined by shrinkage planes.

PETROGRAPHY.

Megascopic characters. — Seen in the outcrop, the rock appears dark gray, coarse grained, and resembles many basic massive rocks in appearance. In the specimen it is seen to be coarsely and evenly granular and to be composed of light and dark constituents, the proportion by bulk being about two of the light to three of the dark minerals. The separation by the heavy fluids shows, however, that by weight the white mineral forms only one-fifth to one-quarter of the whole. The distinction in color is strongly marked and gives the rock a mottled mosaic-like appearance.

Upon examination the dark constituents may be distinguished as chiefly a greenish black augite in columnar masses and aggregates which are never idiomorphic, together with an occasional speck of a bronzy brown biotite of ill-defined outline or a grain of a deep yellow olivine. Filling the interspaces between these dark minerals in formless masses is a very pale greenish gray substance which is leucite. The average size of crystal grain varies from 2 to 5 mm., so that the rock is of quite coarse granular structure, and it resembles most strikingly in fact many coarse-grained gabbros.

Microscopic characters. — The thin section under the microscope shows the minerals present to be *apatite*, *iron ore*, *olivine*, *augite*, *biotite*, *leucite*, and some zeolitic products.

The *apatite* and *iron ore*, which are present rather rarely in moderate-sized grains, show nothing of especial interest beyond that they are found inclosed in the other minerals, and the biotite frequently incloses the iron ore.

The *olivine* is extremely fresh, unaltered in any way, and resembles the olivine of fresh gabbros. It contains great numbers of very fine glass and iron ore inclosures. It never shows any crystal faces, but is in rounded, formless, anhedral grains which are frequently inclosed in biotite and augite.

The *augite* is of a pale green color with a tone of brown; it is very fresh and clear, contains inclosures of ore and specks of biotite and is entirely allotriomorphic, though the

orientation of the ore grains is at times zonal, thus indicating crystal planes. It has an excellent cleavage and twinning bands pass through it in places; it does not show any pleochroism.

The *biotite* is strongly pleochroic between a deep umber brown and a pale yellow brown; it is also entirely allotriomorphic though apt to surround the other minerals in bands, especially the olivine and iron ore. It is particularly characteristic in such cases that it then passes from brown into an olive green variety which has a mottled, somewhat stringy, fibrous appearance. It appears in these cases as if the brown variety had suffered from some magmatic process; it does not seem to be due to any ordinary process of weathering.

Leucite. — The leucite appears also like the other minerals in formless masses filling the interspaces between other minerals. It is perfectly clear and free from all inclusions, except now and then a grain of the ferromagnesian minerals. Between crossed nicols it shows most beautifully the cross-banded twinning structure so characteristic of leucite. It is in general perfectly clear, limpid and fresh, though in some areas, in delicate fringes along cracks and on the borders of grains, a low birefractation shows that processes of zeolitization have commenced. This will be described more in detail later.

As the presence of actual leucite itself has never before been demonstrated, so far as we know, in a granular plutonic rock, it became a matter of importance to prove its identification beyond all doubt.

For this purpose a considerable portion of the rock was crushed, sifted, washed, and treated with the potassium mercuric iodide solution. Immediately all of the ferromagnesian minerals sank, leaving the white component floating. On then lowering the specific gravity by dilution, nothing except an occasional grain fell until 2.465 was reached, when a very little of the white powder came down. This under the microscope proved to consist of isotropic

grains with attached particles of pyroxene and biotite which had evidently increased their specific gravity. This behavior of the rock powder in the heavy solution proves the absence of all feldspars and nephelite, thus confirming the microscopic examination. On now lowering the specific gravity of the liquid to 2.405, the great bulk of the white component came down, leaving a small portion floating. The average specific gravity of this material may be taken as 2.44. Examined under the microscope it was found to be a very pure product, consisting of clear isotropic grains which here and there showed a faint birefracton. An analysis of it gave the following results: —

			Molecular ratios.
SiO ₂	54.46	0.907	0.907 = 4.12 = 4
Al ₂ O ₃	22.24	0.216	0.220 = 1 = 1
Fe ₂ O ₃	0.68	0.004	
MgO	trace	. . .	0.213 = 0.97 = 1
CaO	0.10	0.002	
K ₂ O	18.86	0.200	
Na ₂ O	0.70	0.011	
H ₂ O	2.29	. . .	
	99.33		

The formula is therefore $KAl(SiO_3)_2$ and the mineral is consequently leucite. There appears to be a very slight deficiency of alkalis, and this may be due in part to replacement by water, whose presence is undoubtedly due to processes of zeolitization which are commencing and which may be in part the cause of the faint birefracton noticed above. The small amount of soda shows the leucite to be a very pure potash compound. So far as we know, this is the first analysis of a leucite from other than an Italian locality, with the exception of that given by Steinecke* of the mineral from Choi in Persia.

Zeolitization and a probable new zeolite. — The small portion of powder which was left floating in the heavy solution

* Jüngere Eruptivgesteine aus Persien, Inaug. diss., Halle, 1887, p. 12.

after the precipitation of the leucite at 2.405 was found to come down gradually as the specific gravity was lowered. At 2.357 much had already fallen. At 2.30 a small portion was still floating, and this was then thrown down and analyzed, in the hope of learning what the character of the zeolitization mentioned above had been. Examined under the microscope it was found to consist of isotropic grains, presumably analcite, mingled with a substance of low birefraction. The amount of material was less than 0.4 gram, and of this $\frac{1}{10}$ gram was taken for the determination of water.

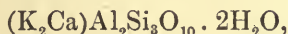
The analysis gave the following results: —

			Ratios.	A.	B.
SiO ₂	50.18	0.836	0.836	4.00	3.46
Al ₂ O ₃	25.07	0.243	0.243	1.16	1.00
Fe ₂ O ₃	trace	. . .			
CaO	1.70	0.030	0.224	1.06	0.93
Na ₂ O	6.53	0.105			
K ₂ O	8.36	0.088			
H ₂ O	9.02	0.501	0.501	2.39	2.06
Total	100.86				

The substance dissolved readily in acid with separation of gelatinous silica. The ordinary analytical errors are of course somewhat magnified by the small quantities operated upon, but as great care was taken it is not believed they are sufficient to affect the ratios. In the first column under A one-quarter of the silica is taken as unity, under B the alumina is taken as unity. It will be seen that the ratio of the protoxides to the sesquioxide to the water is 1 : 1 : 2, as demanded by the analcite formula, but that there is a deficiency of silica. The microscope having already shown that two substances are present, one of them isotropic and most probably analcite, if we consider the soda present as forming that mineral and deduct sufficient silica, water and alumina to make with it analcite, the remainder reduced to 100, becomes: —

	Found.	Ratios.				Calculated.
SiO ₂	45.85	0.764	0.764	3.01	3	44.6
Al ₂ O ₃	26.07	0.253	0.253	1.00	1	25.6
CaO	3.12	0.056	} 0.218	0.86	1	3.4
K ₂ O	15.35	0.162				17.5
H ₂ O	9.61	0.534	0.534	2.11	2	8.9
	<u>100.00</u>					<u>100.0</u>

This yields approximately the formula



which is exactly that of a natrolite $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O}$, in which potash and lime have replaced soda. The ratio of $\text{CaO} : \text{K}_2\text{O}$ is 1 : 2.91 or almost exactly 1 : 3, and the theoretical composition of such a compound ($\text{K}_6\text{CaAl}_3\text{Si}_{12}\text{O}_{40} \cdot 8\text{H}_2\text{O}$) is given above in the column to the right, and it can be seen that the agreement with the amounts obtained is moderately close. If, on the other hand, we assume that the potash yielded by the analysis belongs to leucite and consider it the isometric mineral, then the soda and lime would belong to a mesolite-like mineral, but in that case the agreement of the ratios is very poor and the water entirely too high. The material also floated at a specific gravity of 2.30 and was thrown down below this, which should have excluded leucite, if present in the proportion the amount of potash would indicate. It is reasonable to suppose also that the zeolitization of leucite would yield a potassic compound and not a sodium one. Taking into consideration the mathematical chances against the improbability of the above ratios being accidental and the natural chemical possibility of a potash molecule similar to natrolite, it is not unreasonable to infer that we have a potash zeolite of the natrolite type in this rock.

In thin section this zeolite is seen as small feathery particles of low birefracton running in narrow bands around the leucites and along fractures; it evidently attacks the mineral from the outer surfaces. In places where it has grown into considerable areas, the areas, while they extin-

guish as units, are seen to be composed of a curious grouping of two substances in winding, interlaced, vermicular forms almost exactly like micrographic intergrowths of quartz and feldspar, but excessively fine. Of these two substances one is birefractive, the other isotropic, and from what has already been said it seems probable that they are a mixture of the potash zeolite with analcite.

Occasional separate isotropic grains also occur, which do not show the cross-banded twinning of the leucite, and these are supposed to be also of analcite.

Chemical composition. — A mass analysis of the rock has been made for the U. S. Geological Survey laboratory by Mr. E. B. Hurlburt of the Sheffield Scientific School, which gave the following results (average of two):

	I.	II.	III.	IV.	Ia.
SiO ₂	46.06	47.28	46.73	44.35	0.767
Al ₂ O ₃	10.01	11.56	10.05	10.20	0.097
Fe ₂ O ₃	3.17	3.52	3.53	13.50	0.020
FeO	5.61	5.71	8.20		0.078
MgO	14.74	13.17	9.25	12.31	0.391
CaO	10.55	9.20	13.22	11.47	0.188
Na ₂ O	1.31	2.73	1.81	3.37	0.021
K ₂ O	5.14	2.17	3.76	4.42	0.054
H ₂ O	1.44	2.96	1.24	?	0.080
TiO ₂	0.73	0.88	0.78	?	0.009
P ₂ O ₅	0.21	0.59	1.51	?	...
MnO	trace	0.13	0.28	...	...
BaO	0.32	?	?	?	...
SrO	0.20	?	?	?	...
SO ₃	0.05	...	none	...	...
Cl	0.03	0.18	0.18	...	...
	99.57	100.08	100.54	96.62	
Cl = O	0.01	0.04	0.04	—	
	99.56	100.04	100.50		

I. Missourite, head of Shonkin Creek, Highwood mountains, Montana. E. B. Hurlburt, analyst.

II. Leucite absarokite (Hague, Amer. Jour. Sci., vol. xxxviii, p. 43, 1889). Iddings, Jour. Geol., vol. iii, p. 938, 1895. J. E. Whitfield, analyst.

III. Shonkinite, Square Butte, Highwood mountains (Bull. Geol. Soc. Amer., vol. vi, p. 414, 1895). (With corrected MgO , see p. 424). L. V. Pirsson, analyst.

IV. Leucite basalt, Bongsberg by Pelm Eifel (Hussak, 77 Bd., Sitzb. K. Akad. Wiss. Wien, I Abt., 1878). E. Hussak, analyst.

Ia. Molecular ratios of No. I.

This analysis brings out strongly the leading characteristics of the rock, its very high lime, iron, and magnesia, which have compelled the formation of such quantities of pyroxene and olivine; the predominance of potash over soda, which, with the low silica, have conditioned the formation of the leucite, and which explains also why no feldspars have formed.

The endeavor to compare this rock chemically with the effusive leucite basalts, of which it forms the plutonic representative, has not been entirely satisfactory owing to the lack of accurate and complete analyses of them. A number of analyses exist but are deficient in important determinations, and in some cases it is clear, from what is stated concerning the mineralogical composition, that the separation of the magnesia and alumina is inaccurate, the magnesia being in part thrown down with the alumina. This is unfortunately an all too common error in rock analyses. One of the best is shown in the above table in No. IV, and it will be seen that the agreement is good in the essential details. In No. II is given one of the absarokites of Iddings, with which the missourite, from a chemical point of view, seems to be closely related. In No. III is shown the composition of the shonkinite from the same mountain group. With the same amount of silica in each, the lower alkalies of the shonkinite have permitted orthoclase to form as the dominant white mineral, while their higher amount in the missourite has produced leucite in its place. In the shonkinite the excess of the alumina over the alkalies has gone into the augite and biotite, and the same is undoubtedly true in the missourite. Taking into consideration the ratios shown by the analysis, the separations by the heavy liquid and the study of the

section, the rock has approximately the following mineralogical composition: —

Iron ore	5
Augite	50
Olivine	15
Biotite	6
Leucite	16
Analcite	4
Zeolites	4
	100

Structure. — The structure is purely granitoid, but is not hypidiomorphic since no mineral shows any crystal planes, but all are wholly allotriomorphic. The iron ore, apatite, and olivine commenced forming before the other minerals, but are in rounded anhedral grains; the augite and leucite were crystallizing contemporaneously, as shown by the fact that each incloses grains of the other. In plain light the rock section appears precisely like those of many coarse-grained, massive gabbros, and it is not until the nicols are crossed that it is perceived that the colorless areas are not composed of striated plagioclase but of isotropic leucite.

Classification. — It is clear from what has been said in the foregoing that this rock is a new type, and it fills a place which has hitherto been vacant in all systems of rock classification in which either the texture, structure, and granularity of rocks or their geological mode of occurrence is taken into account. It is the massive, granular, plutonic representative of the leucite basalts and bears the same relation to them that gabbro bears to the ordinary plagioclase basalts or granite to rhyolite. It is closely related to theralite, shonkinite, and ijolite, but cannot be classed under any of these types and must therefore be distinguished by a special name of its own. We have therefore called it *missourite* from the Missouri River, the most prominent and best known geographical object in the region where it occurs.

ANDESITES OF THE AROOSTOOK VOLCANIC AREA OF MAINE.

By HERBERT E. GREGORY.

(From Amer. Jour. Sci. (4), vol. 8, pp. 359-369.)

ANDESITES are rare rocks in the eastern United States, but are the most abundant extrusives so far found in northern Maine. They form prominent hills and determine the general topography in some places, while in others they are represented by isolated remnants among the sedimentaries. The greater number of occurrences are of lava and breccia, but andesitic ash and tuff are also found well developed. In the following descriptions only the more important localities will be dealt with in detail. The andesites are located in Aroostook County in the townships of Chapman, Mapleton, and Castle Hill, where they constitute prominent ridges, known as Edmund's Hill, Hobart Hill, and Castle Hill, and several less noticeable masses.

FIELD DESCRIPTION.

Edmund's Hill Andesites. — Edmund's Hill is situated in Chapman township near the middle of the north township line, and is simply the highest part of a ridge running N. - S. for several miles. The hill itself rises some two hundred feet above the road at its base and presents the outline of a drumlin — so evenly has it been graded at each end. The trees, brush, talus, and glacial deposits entirely conceal the formations about the base of the hill, and it is only after climbing half the distance to the top that the bare rock is found in place. In climbing up the west side of the hill fragments of fossiliferous sandstone were found amongst the andesite blocks, and about one hundred feet below the top

the sandstone ledge outcrops. The thickness and extent of the sandstone could not be determined accurately because covered in so many places with heavy blocks and small fragments of the igneous rock fallen down from above. The contact was not seen. The entire top of the hill is of augite-andesite. The main mass is uniform in texture and cut by cleavage cracks into large blocks which, when they fall down the slope, remain as huge masses. The south and north ends, however, and part of the west side are quite different. Here the rock is split up into long, thin slabs by a set of parallel cracks remarkably uniform in direction and length, and they retain their parallelism even when the rock is folded or faulted. Cross cleavages intersect these cracks every few feet, so that when the rock is loosened it comes out in flat slaty pieces one-quarter inch or so in width and several inches or even feet in area. The whole appearance is that of thin-bedded sedimentaries which have been folded and faulted. The general direction of these cleavage planes is N. 30° E. on north end and N. 35° E. on south end with a dip southeast at a high angle. The fault planes strike N. 70° E. and besides their effect at the ends of the hills in cutting out the thin slabs they occur all along the west side, each indicating a slight movement. It seems probable that the Edmund's Hill ridge owes its origin in part to the formation of a fault block.

The outlying knobs and hills to the east of the main mass are also of andesite, usually microcrystalline, but sometimes porphyritic. The igneous rock does not extend far to the west, but is replaced by arenaceous slates, and while no precise boundaries of the formation were determined, the field relations suggest that the hill is the remnant of a lava flow over the eroded and upturned edges of sandy rocks of Silurian age.*

Andesites of Hobart Hill. — This hill is an isolated mass of andesite forming a prominent feature in the landscape as

* The sandstone at Edmund's Hill contains an Eodevonian fauna which corresponds closely with that of the Gaspé sandstone.

one looks west from Presque Isle village. It is situated partly in Mapleton and partly in Chapman townships, and is surrounded entirely by low, poorly-drained swamps and forest lands, and visited only for lumber and tan-bark, which are secured in limited quantities during the winter season. The hill is about one and a quarter miles long and three quarters of a mile wide, and rises quite abruptly above the plain to a height of three hundred feet as a single well defined mass without branches or outlyers. The sides are everywhere quite steep, and in places present cliffs forty to fifty feet high. The top is bare only where fire has recently destroyed the vegetation. The talus slopes present a confused mass of large and small blocks of andesite which entirely conceal all outcrops except where cliffs are exposed. On the west and north sides numerous boulders of red sandstone and conglomerate are piled along the slope and mingled with the volcanic material. These were traced to their parent ledges scarcely a half-mile to the north, and the boulders serve to cover the contact of the andesite with the Mapleton sandstone.* Specimens collected from various places on the hill show but slight differences in composition and texture except the rock from the northwest corner, which is a breccia of andesitic fragments and seems to be situated along a fault line. As was the case with Edmund's Hill, so here, no actual contact between formations was observed, but the sedimentaries were traced to the very base of the hill, and the facts indicate that the hill is a remnant of a lava flow.

Andesites of South Mapleton.—In addition to the prominent hills of andesite just mentioned, there are some ten or twelve less conspicuous outcrops in the southern part of Mapleton township crossed by the Mapleton-Presque Isle road and located in the fields to the north and the south of this road. They occur usually as narrow ridges, and seem to be remnants of lava flows which occupied former valleys, but are now left

* The "Mapleton sandstone" here referred to is a massive, and in places coarse, red sandstone, in which plants (*Psilophyton*, etc.) have been found. It is of Devonian age, but somewhat younger than the Chapman sandstone.

standing because of the erosion of the sedimentaries on both sides.

Andesites of Castle Hill. — Castle Hill is the local name for the northern end of the high, narrow ridge extending N.-S. across the township with the same name. While not such a conspicuous feature as Haystack Mountain at the southern end of the same ridge, it forms the most considerable prominence on the immediate bank of the Aroostook River along which route all the early travel lay, and hence was an important landmark to the first settlers. There is no common local usage as to the limits of Castle Hill, and in this report the term will be applied to the masses of andesite and volcanic clastics which lie between the Aroostook River and the "State Road" from Ashland to Presque Isle. It covers an area $2\frac{1}{2}$ miles long varying in width from $\frac{1}{2}$ to $\frac{3}{4}$ mile, and is partly in Castle Hill township and partly in Wade plantation. The wagon road crosses the hill at its southern end, where it rises little higher than the surrounding plain. The eastern side has a gentle slope, and is cut up into several low knobs by small streams, so that the ridge effect is not apparent. The west side is formed by Welt's brook and the Aroostook River, which at this point is forced by it to take the abrupt backward turn so noticeable on the map. Calcareous and arenaceous slates are exposed in the bed of the river, while a short distance back steep slopes and cliffs of lava and ash rise to a height of several hundred feet. The hill is densely wooded and in places swampy, except at the southern end and along the east side. At these points the bare rocks are occasionally exposed and present a great variation in character. In one place heavy ledges of gray andesite are exposed, particularly on the knobs occupying the northwest and southeast corners of Lot 31. Again in the woods east of the mouth of Welt's brook is an outcrop of black silicified tuff between slates. On the southeast corner of the hill are loose ash beds containing fossils, coarse and fine volcanic breccias, and pumiceous lava in quite fresh condition. Where the glaciers have planed off the old lavas and they have been protected from weathering, the outlines of bombs and pillows

are plainly revealed, and when weathered these bombs are loosened and drop out as oval or egg-shaped bodies with amygdaloidal surface and denser interior, and lie about thickly strewn the fields. In one place there is a cistern-like depression some ten feet deep and thirty feet in diameter made in the solid andesite, while about it are piled close at hand a great number of very vesicular bombs and much glassy and brecciated ash. The whole appearance suggests a small blowhole made by a single explosion. The striking fact about all the volcanic accumulations in the Castle Hill region is their freshness and their unmistakable character.

PETROGRAPHY.

Generally speaking, the andesites of this region belong to well-recognized varieties widely distributed over the earth and differ in no important particulars from the type rocks of their class. There are varieties found here, however, which are intermediate between andesites and trachytes and also occurrences with dacite facies. The exposures are numerous and easy of access and the specimens are no more altered in composition than if they were Tertiary lavas instead of Paleozoic.

Augite-Andesite—Macroscopic description.—The largest and best single exposure of andesite in this region is of this variety and forms the main mass of Edmund's Hill. It does not occur as a solid compact mass, but is broken by cleavage and shearing planes into large blocks on top, and into plates and slated material at the ends of the hill. This slated and seemingly bedded appearance, which is so unusual in an igneous rock, is the most marked peculiarity of the structure of the hill. In a few places the rock is seen to contain embedded angular pebbles of glass and baked siliceous material which stand out when it weathers; and in other places the rock presents a banded surface of gray and brown, giving the appearance of bedding, but which proves on examination to be varying stages of decomposition along potential cleavages. With these exceptions the exposed rock has a uniform appearance, gray where weathered, black where fresh.

Andesites are so well known that an extended macroscopic description is unnecessary and will not be attempted. The hand specimen appears as a black, basaltic-looking rock, generally dense, with a stringy effect and sprinkled over with glassy feldspars 2 mm. and less in length. The weathered surface is a layer of spongy, gray-brown material in which the pores are made by the decay of the larger feldspars. At the east end of the hill the rock is much lighter in color, and numerous white feldspars give it a more porphyritic appearance.

Microscopic. — As with the hand specimen, so microscopic examination reveals the composition and structure expected of a typical andesite. Magnetite, apatite, pyroxene, plagioclase, and orthoclase are the original minerals present. The plagioclase crystals range in size from laths 2 mm. in length down to the very fine ones in the ground-mass, but the larger ones are not abundant and do not give the rock a porphyritic aspect. The plagioclase forming the crystals outside the ground-mass was determined by Michel Lévy's method to be labradorite; but the measurements indicated two labradorites with the formulæ: Ab_3An_4 and Ab_5An_6 . The larger feldspars show strongly marked zonal banding with occasionally as many as eight distinct zones, which decrease in basicity from the centre outward, but with the original albite twinning running through the whole series. This albite twinning shows in nearly every feldspar lath with great distinctness, and twins on the pericline and Manebach laws also occur. The Carlsbad twins present are often with one-half dropped much below the other, and all the twinning is more or less along irregular ragged lines and with unsymmetrical development. None of the feldspars are entirely fresh, but are kaolinized along the cleavages and zonal boundaries, or entirely altered to kaolin and calcite except their outer borders. They also show irregular cracks other than cleavage along which strain has been relieved. Glass inclusions, arranged without order, are numerous and stand out prominently in the clearer parts of the feldspars. Orthoclase was not found outside the ground-mass except as forming the wide outer rim of the zonally-built plagioclases.

The *Pyroxenes* are of both monoclinic and orthorhombic varieties. The monoclinic is an augite, light colored in thin section and having an average extinction on prism sections of 42° . The basal sections are quite fresh and show the cleavage parallel to the prism. The pinacoids are more developed than the prism faces and give the appearance of a square with truncated corners rather than the more common octagonal effect. The prism sections vary from stout forms to those five or six times as long as broad. In places many small pieces are arranged in parallel position and separated by alteration products in such a way as to suggest the presence of augite phenocrysts of which these fragments are the remnants. The orthorhombic pyroxenes are represented in the darkest colored rocks by a few basal and prism sections, but in the gray varieties it constitutes fully half of the pyroxenes present. It is very light colored, not at all pleochroic, and is at times partly eaten away and again occurs as parallel intergrowths with the augite. It seems to be a variety poor in iron, is optically +, and hence referred to enstatite. In the fresher rock specimens the cleavage cracks and borders of the enstatite often show the presence of a red-brown fibrous mineral. In the more weathered rocks this mineral assumes a prominent rôle. It is here found intergrown with augite and forming fibrous laths with parallel extinction. Its pleochroism is distinct with α = light brown, ϵ = light green. The presence of this mineral in a slide seems to be in proportion to the absence of the orthorhombic pyroxene, and this fact, together with its shape and optical properties, point to bastite and make the supposition plausible that the red-brown mineral is the present representative of the original orthorhombic pyroxene. The magnetite is present in grains or dust aggregates, and the apatite occurs in needles, laths, and rounded sections within the feldspars.

The *ground-mass* consists essentially of feldspar laths, long, narrow, with ragged outline and split ends, arranged with trachytic structure tending toward the hyalopilitic, and with flow phenomena developed in places. No close distinction

can be drawn between the ground-mass feldspars and those which rise slightly above it, as all sizes are represented grading up to the very largest ones present. Optical measurements on some of the freshest pieces in the ground-mass proved them also to be labradorite, although orthoclase must also be present as demanded by the analysis. Besides the feldspars, augite grains are scattered abundantly throughout, and small areas of brown glass, occasionally with bubbles, also occur. The whole slide is darkened by iron dust, both magnetite and limonite or göthite. The rock is, however, in a remarkably fresh state considering its age and position, and its character is unmistakable.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO ₂	61.40	61.58	61.29	61.04	61.45	61.17	63.25
Al ₂ O ₃ . . .	16.59	16.96	17.68	15.72	15.07	17.74	14.89
Fe ₂ O ₃ . . .	2.13	1.75	6.03	5.03	4.46	1.78	6.54
FeO	3.05	2.85	0.30	2.15	1.18	3.51	none
MgO	2.73	3.67	2.45	3.61	3.02	2.76	0.82
CaO	6.17	6.28	5.61	5.34	5.37	5.90	0.59
Na ₂ O	3.83	3.94	4.28	4.02	4.00	3.79	4.47
K ₂ O	1.34	1.28	1.38	2.66	1.22	1.71	4.78
H ₂ O — 105°	0.82	0.24	0.96	0.58	1.23	0.83	2.67
H ₂ O + 105°	0.88	1.06					
TiO ₂	0.79	0.49	0.65	...	...	0.45	trace
ZrO ₂	none	...	...	...	...	...	...
Cr ₂ O ₃ . . .	trace	...	...	...	...	none	...
V ₂ O ₃	0.02	...	...	...	...	...	...
NiO	trace	...	...	...	...	...	...
MnO	0.13	trace	...	...	none	0.12	...
BaO	0.02	0.03	...	...	...	0.06	...
SrO	trace?	trace	...	...	...	0.04	..
Li ₂ O	trace	trace	...	...	0.05	trace	...
P ₂ O ₅	0.20	0.22	...	...	trace	0.14	0.61
CO ₂	none	...	...	...	...	...	0.78
Cl	?	...	...	...	...	...	...
Fl	?	...	...	...	...	...	...
FeS ₂	none	...	...	...	SO 3 0.29	...	loss
						...	0.53
	<u>100.10</u>	<u>99.23</u>	<u>100.63</u>	<u>100.15</u>	<u>100.14</u>	<u>100.00</u>	<u>99.93</u>

I. Andesite, Edmund's Hill, Aroostook Co., Maine. Analysis by W. F. Hillebrand.

II. Hornblende andesite, Mt. Shasta, Cal. Analysis by N. H. Stokes, Bul. U. S. Geol. Survey, 148, p. 190.

III. Hornblende dacite, Anzeiou, Ægina. Analysis Dr. A. Röhrig, H. S. Washington, Jour. of Geol., vol. iii, p. 150.

IV. Pyroxene andesite, Peñon de Pitayo, United States of Columbia. Küch: Geol. Studien in der Republik Colombia, Pt. I. Berlin, 1892.

V. Pyroxene andesite, Agate Creek, Yellowstone National Park. Analysis by Whitfield, U. S. Geol. Survey, Bul. 148, p. 134.

VI. Hypersthene andesite, Crater Peak (Lassen Peak Region). Analysis by W. F. Hillebrand. U. S. Geol. Survey, Bul. 148, p. 197.

VII. ?Andesite, Fox Islands, Maine. Analyses by E. W. Magruder and W. A. Jones in Johns Hopkins University Laboratory. G. O. Smith, Geol. of Fox Islands, Maine. Presented as a thesis, Johns Hopkins University, 1896.

Analysis. — The analysis of this rock made by Dr. W. F. Hillebrand of the U. S. Geol. Survey is given in column I below, and with it analyses (columns II–VI) of well-known andesites from other localities are given for comparison.

From a study of the tables it becomes apparent that the Edmund's Hill rock presents no points of distinction from recognized types found elsewhere, and the tables could be greatly enlarged by the addition of closely similar analyses. The analysis in column VII requires some notice. The rock is described as a red andesite with "rather basic" feldspars and with calcite and magnetite present. The altered condition of the rock made accurate optical determination impossible. In discussing the analysis the writer says (l. c., p. 34), "In its mineralogical composition, this rock approaches the basaltic type, but, as the analysis shows, is somewhat too acid. The olivine phenocrysts, moreover, are not very numerous and there is reason to regard this as simply an olivine-bearing phase of the andesite." The description is of an andesite, but there are discrepancies

between the description and the analysis. No ferrous iron is present to form magnetite, and if the small amount of lime forms calcite, basic feldspars could not be produced. And even if the whole 0.59 per cent of lime were present as andesine or labradorite the amount is far too small for an andesite. According to the generally-accepted usage among petrographers, a rock with such a high percentage of soda and potash with little lime and magnesia would be classed as a trachyte or more closely, an ægerine-trachyte.

Hornblende-andesite. — The largest single mass of this rock is Hobart's Hill, and the freshest and most typical specimens are from this hill and from the west bank of the Presque Isle near the northwest foot of the hill, where quarrying was attempted at one time. The hand specimen shows a very dark gray, almost black, rock, fine-grained, but with a somewhat porphyritic appearance caused by the occasional feldspar crystals which rise above the general ground-mass and reflect light well from their glassy cleavage faces. Some few feldspar laths attain a length of 5–6 mm. The rock breaks out into tabular blocks along the cleavages and weathers to a brownish gray color.

Microscopic description. — In thin section the microscope reveals magnetite, apatite, titanite, rarely a zircon lath, possibly augite, hornblende, plagioclase, and orthoclase together with considerable secondary calcite. The feldspars range from 2 mm. in length down to minute microlites. The larger feldspars are commonly converted to calcite, which while it indicates their basic character, also prevents their accurate determination. Those which could be measured by the Michel-Lévy method proved to be andesine with formula Ab_1An_1 , hence more acid than the feldspars of the augite andesine. They contain glass inclusions, are zonally built with an occasional unaltered outer border, and are twinned according to the Carlsbad and albite laws but with very irregular intergrowths of the parts.

Hornblende is the only important ferro-magnesian mineral present and occurs, like the feldspars, both as large basal

sections and long laths often with good crystal outline and also as shreds in the ground-mass. The larger pieces are rarely in a good state of preservation, but occur with ragged edges and show resorption phenomena. The crystal is eaten into and part of the interior converted into magnetite with a few augite grains. Some crystals have been almost entirely replaced by calcite and magnetite, and others are represented by a ghostlike outline of magnetite dust. Commonly the hornblende is now changed to a green micaceous material, perhaps a variety of chlorite, with parallel extinction and a pleochroism, ϵ = white green, α = brown green. At times the former crystal is striped across with alternating bands of green and white in the direction of the cleavage cracks. Some of the crystals classed as hornblende are so altered that it is impossible to say that they may not be augite.

The ground-mass is formed of small, stringy, ragged feldspars and varies in different slides from trachytic or pilotaxitic, with possibly a little glass, to a type formerly quite glassy and showing devitrified areas with incipient micro-poikilitic structure. The feldspar microlites could not be accurately determined, but their average extinction indicates a variety as acid as oligoclase-andesine, and if strict nomenclature were to be considered, the rock would be classed as a trachyte-andesite.

Andesites of Southern Mapleton. — These occur in several localities and are either identical with, or present only minor variations from, the Edmund's Hill and Hobart's Hill masses. The rock which outcrops in the road two miles east of Mapleton village has the most glassy ground-mass of all the andesites, and its devitrified areas have the micropoikilitic structure the best developed. Two outcrops show a type much lighter in color with much secondary and some original quartz, giving the rock a dacite facies. The other sections examined are of the typical augite-andesite or hornblende-andesite of this region, and require no detailed description.

Andesites of Castle Hill — Macroscopic description. — The

rocks at this place do not have the character of lavas which have formed thick flows, but suggest rather the surface of a flow and are commonly amygdaloidal, or even slightly brecciated and ashy, and associated with them is an abundance of true volcanic ash with lapilli. The rock exposed at the southeast base of the hill is striking in its field appearance. Black, rusty-looking, spheroidal or elliptical masses of lava, one to two feet in diameter, first attract the attention as they lie loosely strewn over the surface. The solid ledge itself is seen to be composed of these forms, which have their outlines well displayed by weathering. These sack-like or pillow-shaped masses are plainly amygdaloidal on the surface, but usually much denser in the interior and are cemented together by a coarse breccia of rough tabular, spheroidal, or irregular jagged fragments of glassy material and igneous rock of similar composition to the spheres. In some places, noticeably on McDonald's hill to the south of Castle Hill proper, this structure assumes the form of a conglomerate of small amygdaloidal spheres six inches and less in diameter, closely cemented together with angular pebbles of andesite and other igneous rocks. Similar structures have been described from California,* and from Scotland† and elsewhere. As noticed by Geikie, some basic lavas, *e. g.*, the basalt at Acicastello in Sicily,‡ on flowing into water or a watery silt, assumes a remarkable spheroidal or pillow-shaped structure, "the spheroids being sometimes pressed into shapes like piles of sacks." This may be the explanation in the present case. Another interpretation is that the structure represents the ropy rolling surface at the front of a lava flow. On a fresh surface the rock is dark bluish-gray, uniform in texture or with a rare feldspar phenocryst. While this appears to be the most typical of the textures, it is usual to find vesicles now filled with calcite and fragments of volcanic debris large

* Ransome: Bull. Départ. Geol. Univ. of California, vol. i, p. 106. Fairbanks: Bull. Départ. Geol. Univ. Cal., vol. ii, p. 40.

† Geikie: Ancient Volcanoes of Gt. Britain, vol. i, p. 193.

‡ Johnston-Lavis: South Italian Volcanoes, p. 41.

enough to constitute a conspicuous feature in the hand specimen. In weathering, the amygdaloidal parts go first and leave the more dense igneous and glassy pebbles exposed as a very rough surface.

Microscopic description. — Sections were cut from the densest material and also from that with macroscopic inclusions, and when examined with the microscope showed no difference except in size of vesicular areas and in method of alteration. Feldspar microlites make up the rock, parts of which are developed as areas of vesicular lava. The vesicles range in diameter from 2 mm. to microscopic dots and are rudely oval in outline. The large ones are merely the larger part of a rounded area of vesicular glassy lava, containing a few feldspar threads like the body of the rock. Sometimes instead of one vesicle, filled with calcite, the same space will be occupied by a group of them, or the concave inner border of the large one may indicate its formation from several smaller ones. Some glassy oval areas occur with vesicles visible only under the highest powers. All these variations are doubtless caused by the fact that different sections of similar vesicular areas are exposed in the preparation of the slide. The only feldspar phenocryst seen in the sections is rounded in outline, has albite and pericline twinning, and is badly altered to calcite. Its extinction-angle indicates albite or andesine, and, from the fact that phenocrysts are usually more basic than the components of the ground-mass, is referred to andesine. No ferro-magnesian mineral is present, but the numerous patches of chlorite and the fact that augite occurs in similar rock in the immediate neighborhood points to the former presence of pyroxene. Besides chlorite, there are present as secondary products calcite, a few epidote grains, and abundant iron ore. One slide is sprinkled full of stringy black iron ore in long threads or lines of partly connected dots which are arranged to form barbed arrows or a network of fibers which cross at angles of 60° and 90° , thus imitating the sagenite structure of rutile.

The ground-mass is of long, stringy, narrow, frayed out

microlites of feldspar with trachytic structure. Measurements of many laths gave, practically, a parallel extinction, thus indicating oligoclase. Expansion structure is developed where the vesicular areas are large enough to affect the orientation of the minute laths constituting the main body of the rock.

Andesite Ash Beds. — Beds of volcanic ash of an andesite character are represented in the region covered by this paper. They are particularly abundant about Castle Hill, and will be discussed in another place.

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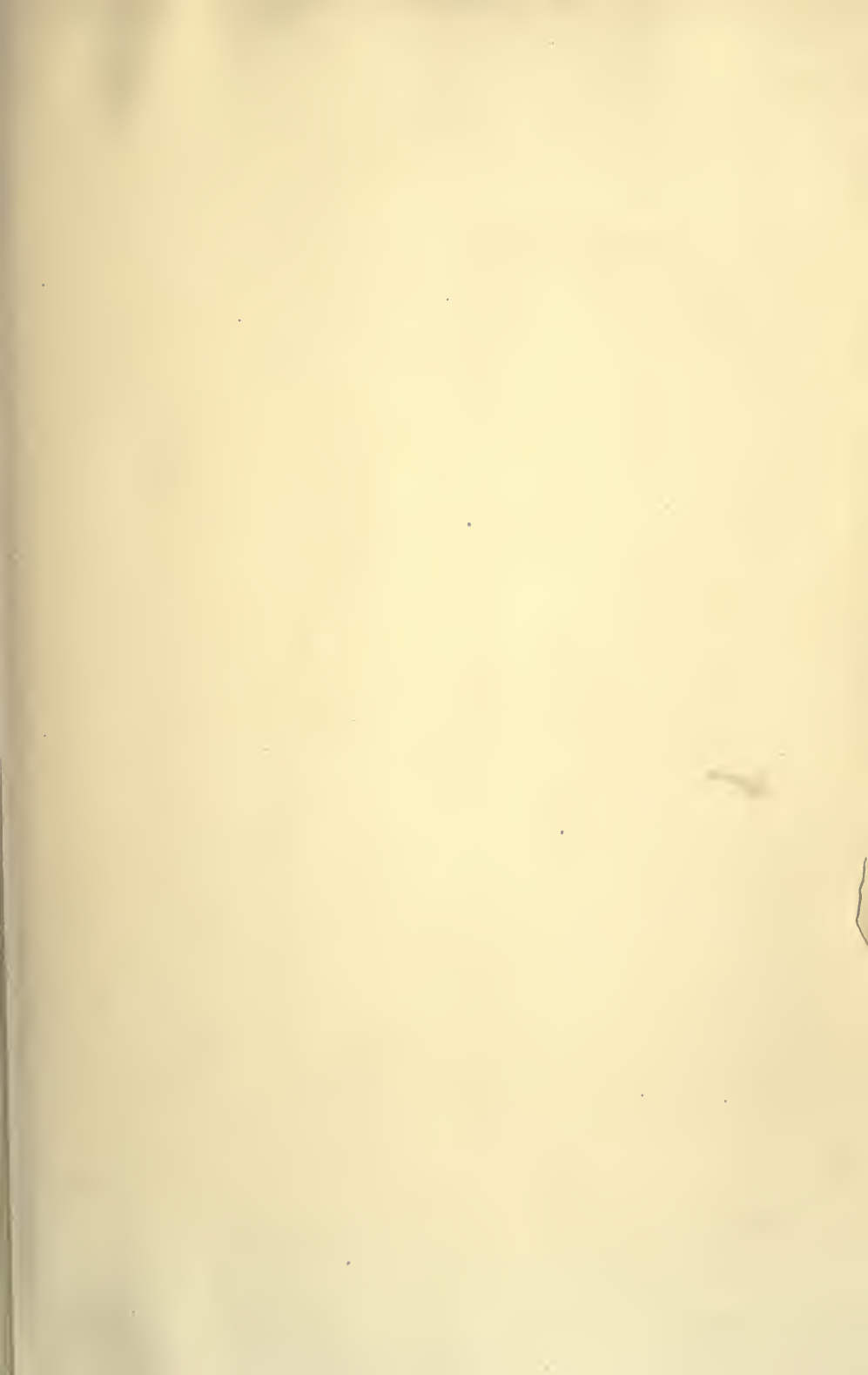
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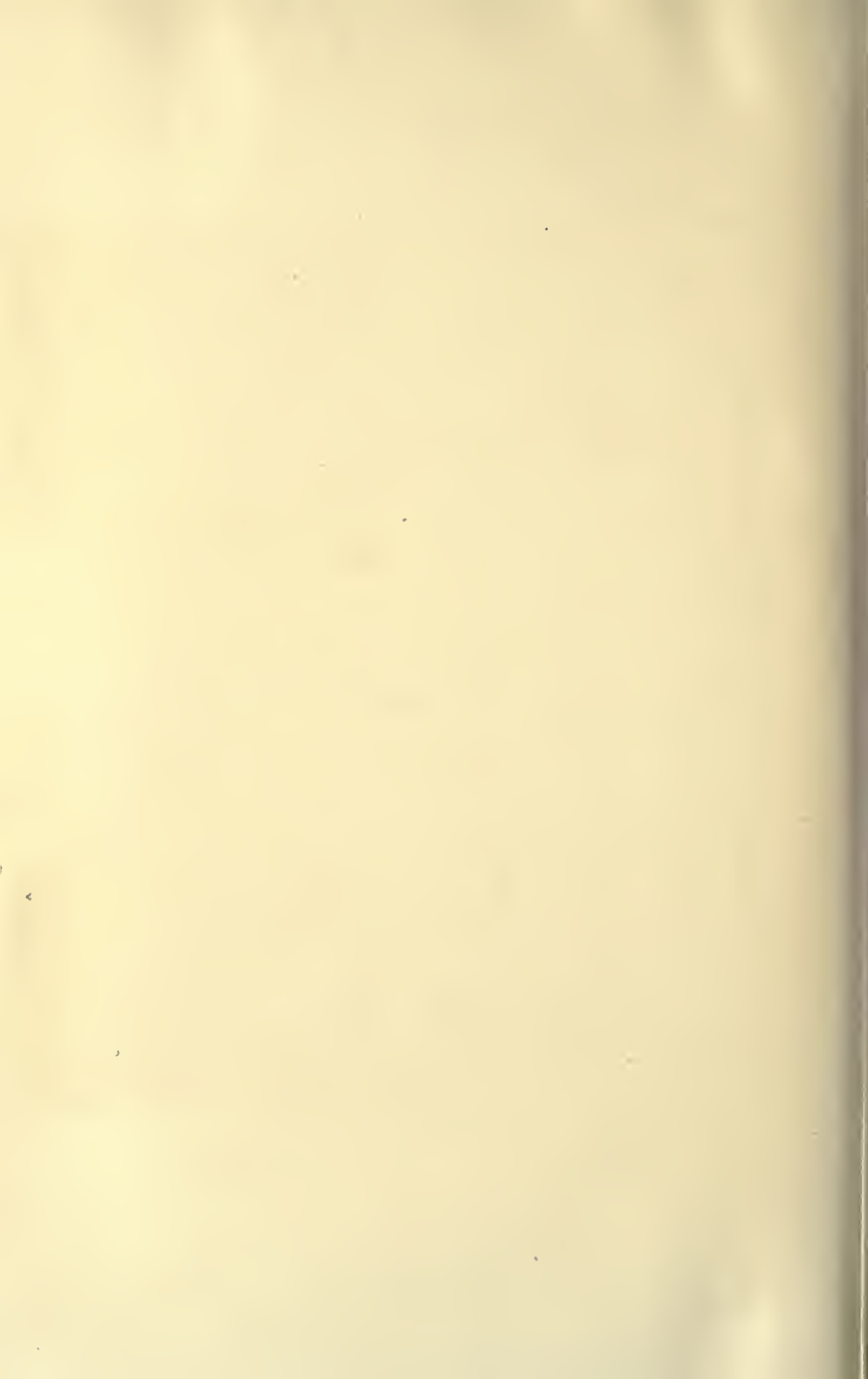
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